STRATIGRAPHIC AND PALEOENVIRONMENTAL INTERPRETATION OF COCCOLITHS FROM OCEAN DRILLING PROGRAM SITE 647, LABRADOR SEA

UL-SUNG YI

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STRATIGRAPHIC AND PALEOENVIRONMENTAL INTERPRETATION OF COCCOLITHS FROM OCEAN DRILLING PROGRAM SITE 647, LABRADOR SEA

BY

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ABSTRACT

A total of 18 coccolith species was identified in the upper ca. 55 m of Ocean Drilling Program Site 647, Hole B (cores 1H to 6H) and the upper 1.1 m of gravity core Hudson 84-030-003. E. huxleyi Zone (NN 21), G. oceanica Zone (NN 20) and the upper part of P. lacunosa Zone (NN 19) were recognized at 0 to 11.1 m, 11.1 to 21.8 m and 21.8 to 56 m, respectively. The biostratigraphic zones were identified primarily based on the FAD of E. huxleyi and the LAD of P. lacunosa which are found to occur at the lowermost part of oxygen isotopic stage 7 and at the lowermost part of oxygen isotopic stage 12.

Total floral record indicated that i) glacial and interglacial stages are characterized by minimum and maximum coccolith abundances, respectively; ii) early phases of several glacial stages are characterized by relatively high coccolith abundances; and iii) a few glacial to interglacial stage transitions are barren of coccoliths. These barren zones may be the result of dilution by terrigenous sediments or/and the result of suppressed biogenic carbonate productivity by the input of low-salinity and low-nutrient melt waters during deglaciation. The floral assemblages indicated that the study area was dominated by subpolar and transitional water-masses from 0 to ca. 0.472 Ma (oxygen isotopic stages 1 to 12/13) and by transitional water-masses from ca. 0.472 to ca. 1.076 Ma (isotopic stages 12/13 to 35/36). The floral assemblage data also showed that early phases of several glacial stages are characterized by the presence of transitional or subpolar water-masses, indicating possible northward advection of warm North Atlantic water during the initial period of Northern Hemisphere ice sheet growth.

R-mode cluster and factor analyses recognized an environmentally significant floral group consisting of C. pelagicus, E. huxleyi and G. oceanica.

The floral group may reflect possible interactions between the cold Labrador Current and the warm North Atlantic Drift or coexistence of the two currents in the southern Labrador Sea during the interval studied. Q-mode cluster analysis recognized the most significant floral change slightly above the top of Jaramillo magnetic event, ca. 0.91 Ma when the dominant species, C. doronicoides was replaced by G. caribbeanica. It is interesting to note that the stratigraphic level marked by this floral change approximately coincides with the mid-Pleistocene interval ca. 0.9 to 0.6 Ma marked by the shift in climatic response of the North Atlantic from 41,000 years to 100,000 years periodicities (Ruddiman, Backman et al., 1987).

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Finally, I am greatly indebted to my parents in Korea for their unsurpassible love and moral support. My wife, Ju-hwa and my son, Sang-min have shown an unfaltering patience in enduring all the difficulties and inconvenience brought about by a self-absorbed husband/daddy during the period of this study. Without their love, patience and help, this study would not have been possible.

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CHAPTER 1

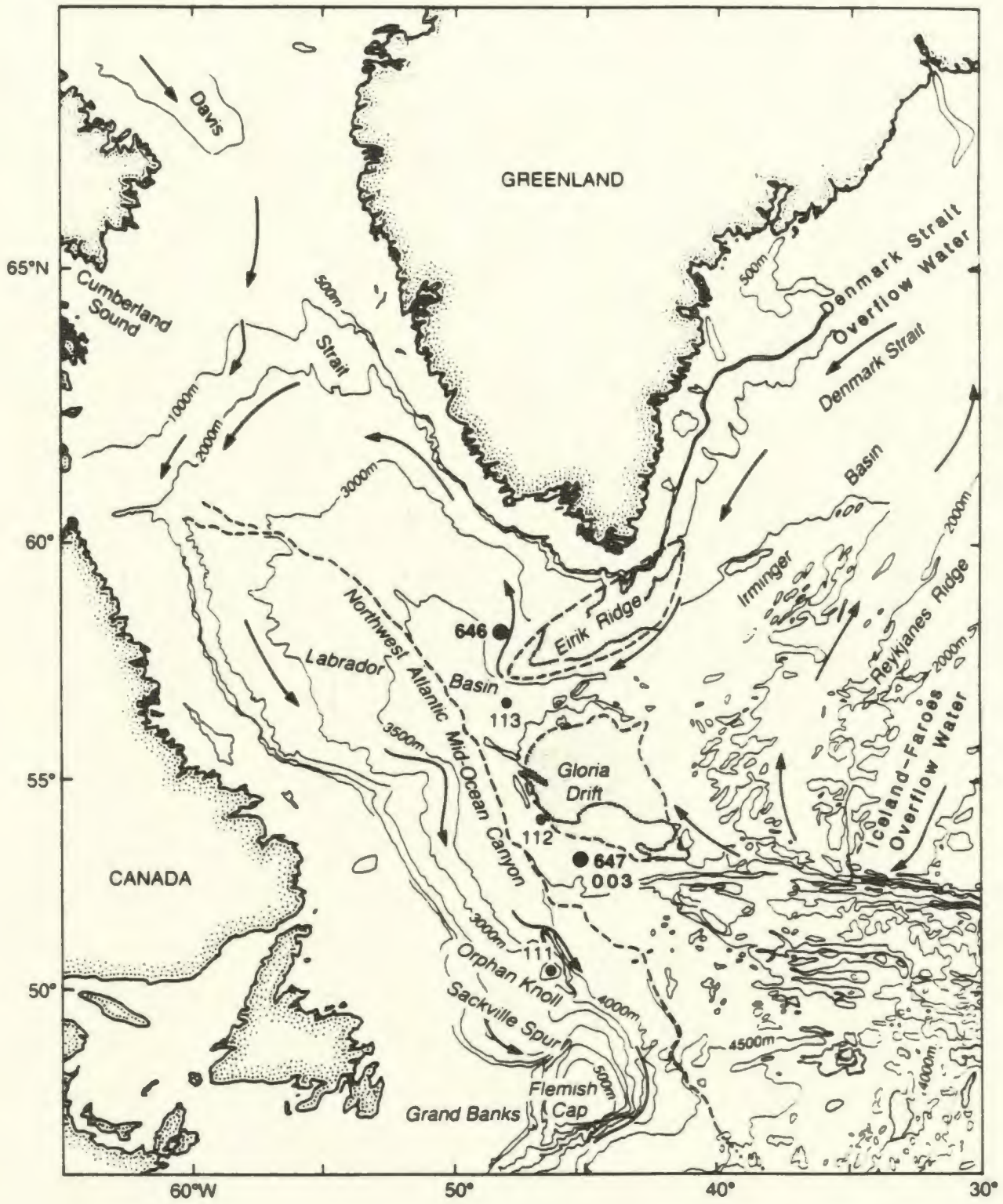
INTRODUCTION

Labrador Sea, located between 50° and 60° N latitudes, is the northwestern extension of the Atlantic Ocean (Fig. 1.1). The Labrador Basin is confined by the shelf break at approximately 200 to 500 m water depth and maximum depth increases gradually from 2,500 m in the northwest to more than 3,800 m in the southeast. The Northwest Atlantic Mid-Ocean Canyon (NAMOC), which has a morphological characteristic of a channelized meandering talweg on the abyssal sea floor, runs toward the southeast through the entire basin (Chough, 1978).

During the Ocean Drilling Program (ODP) Leg 105, two holes (Hole 647A and Hole 647B) were drilled at Site 647 (53°19'N 45°15'W) (Fig. 1.1). The site is located in the southern Labrador Sea, ca. 100 km south of the Gloria Drift at a water depth of 3858 m. The Gloria Drift is one of the major sedimentary drift deposits formed by contour currents in the high latitude North Atlantic (Srivastava, Arthur, Clement et al., 1987). Site 647 is located off the main axis of the drift deposit to avoid drilling the thicker drift sequence and penetrate older sedimentary units at shallower depth (op. cit.). At present, the overlying region of the site lies in a position that is influenced by both cold Labrador Current and warmer North Atlantic Drift waters (Fig. 1.2).

The present winter atmospheric circulation pattern in the region surrounding the Labrador Sea is related to above average winter temperatures in Greenland and western North America and to below average winter temperatures in eastern North America and western Europe (Crowley, 1984). The winter circulation pattern, which is called the "Greenland Above" circulation pattern, is characterized by southward flow of polar air in northeast Canada and northward flow of relatively warmer air in the northwest Atlantic.

Fig. 1.1. Bathymetric map of the Labrador Sea, showing ODP Sites 646 and 647, Hudson 84-030-003 and DSDP Sites 111, 112 and 113 and deep-water circulation (arrows) (from Srivastava, Arthur, Clement *et al.*, 1987).

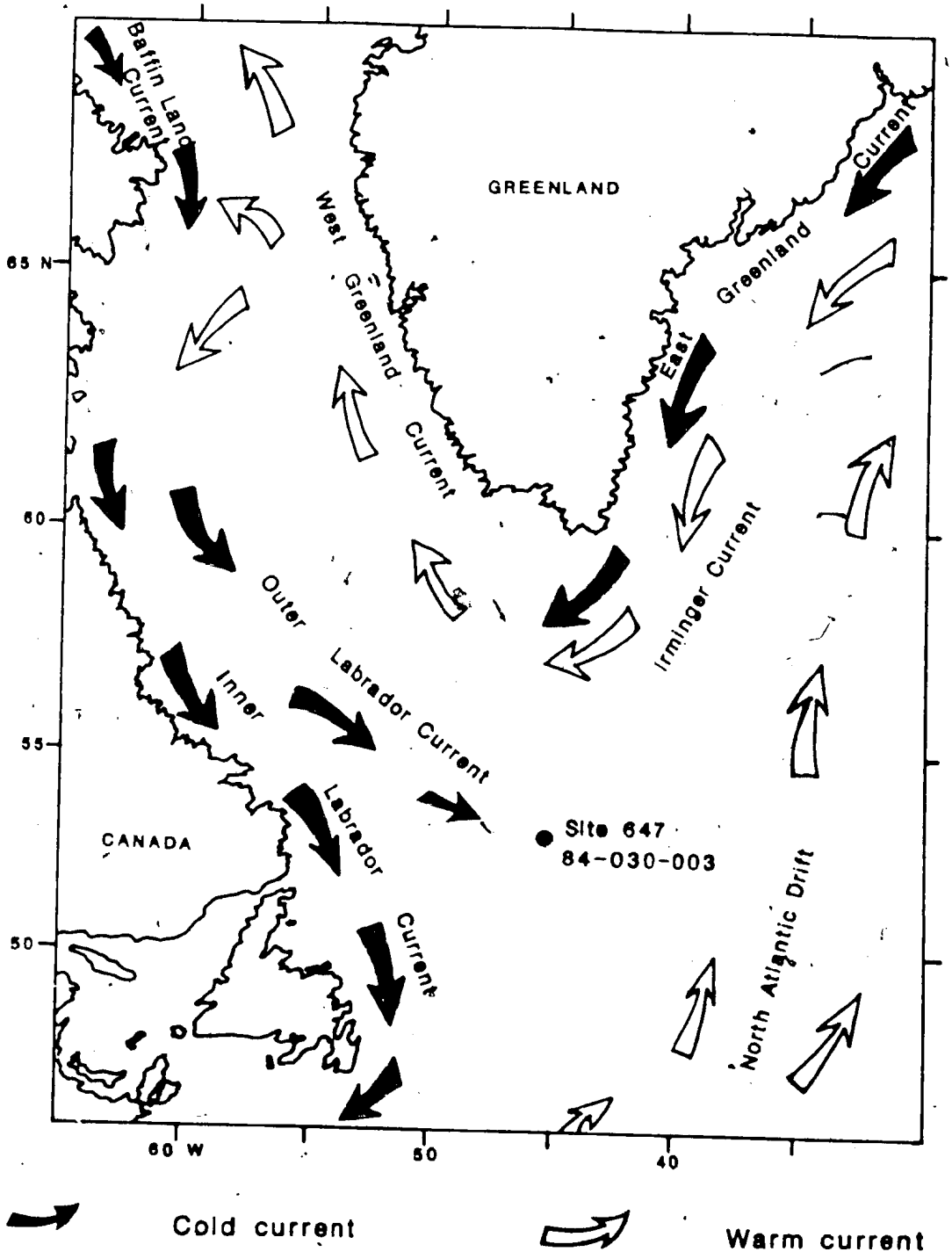

GREENLAND
CANADA
Davis
Strait
Cumberland Sound
1000m
2000m
3000m
500m
Denmark Strait
Overflow Water
Denmark Strait
Basin
Irminger
Reykjanes Ridge
2000m
Iceland-Faroes
Overflow Water
Northwest Atlantic Mid-Ocean Canyon
Labrador
Basin
Eirik Ridge
646
113
112
647
003
111
Gloria Drift
3500m
Orphan Knoll
Sackville Spur
Flemish Cap
Grand Banks
4000m
4500m
65°N
60°
55°
50°
60°W
50°
40°
30°

The northward flow of warm air in the northwest Atlantic is associated with warm subpolar ocean temperatures, low sea ice in the Davis Strait, and increased snowfall over northeast Canada (op. cit.). The increased snow cover over northeast Canada, coupled with minimum Northern Hemisphere summer insolation, may trigger an ice age (op cit.). Based on these features, an amplification of the present "Greenland Above" circulation pattern could be a good model for the paleocirculation pattern which brought about Late Cenozoic Northern Hemisphere glacial inception (op. cit.). Therefore, the Labrador Sea is an ideal location to study air-ocean-ice interactions in Northern Hemisphere during the Quaternary.

1.1. CIRCULATION AND WATER-MASSES

The surface water circulation in the Labrador Sea is characterized by the western bulge of the counter-clockwise subpolar gyre in the high latitude North Atlantic (Fig.1.2). The West Greenland Current (3-6°C; 31-35‰ salinity), comprising a mixture of cold Arctic water from the East Greenland Current and warmer Atlantic water from the Irminger current, flows northward along the west coast of Greenland (Lazier, 1973; Pickard and Emery, 1982). In summer, the West Greenland Current flows northward into Baffin Bay and eventually joins the southward flowing cold (-1 to 1°C) Baffin Land Current (Ivers, 1975). In winter, the cold Baffin Land Current displaces the West Greenland Current southward and dominates most of the northwest Labrador Sea and Baffin Bay (Coachman and Aagaard, 1974). In southern Davis Strait, the Baffin Land Current joins a branch of the West Greenland Current and forms the Labrador Current, which is characterized by temperatures of <3.5°C and salinities of 30 to 34‰ (Ivers, 1975; Pickard and Emery, 1982). The inner Labrador Current consists of both coastal runoff and cold Arctic water and flows southward along

Fig. 1.2. Surface-water circulation of the high-latitude northwest Atlantic.


Baffin Land Current
GREENLAND
West Greenland Current
East Greenland Current
65 N
60
55
50
Outer Labrador Current
Inner Labrador Current
Irminger Current
CANADA
Site 647
84-030-003
North Atlantic Drift
60 W
50
40
Cold current
Warm current

the east coast of Labrador and Newfoundland, whereas the outer Labrador Current consists of warmer and more saline water and flows southeastward. During the winter months between December and March, the inner Labrador Current lies in a sea-ice condition, while the outer Labrador Current lies in a sea-ice free condition and forms a cyclonic gyre in the southern Labrador and Irminger Seas. In the southern Labrador Sea the warm (>5°C) and saline (about 35‰) North Atlantic Drift flows northeastward as an extension of the Gulf Stream (Lazier, 1973).

Deep water circulation in the Labrador Sea is dominated by the Denmark Strait Overflow and Iceland-Faeroe Overflow Waters (Fig. 1.1). The cold (-0.5°C) Iceland-Faeroe Overflow Water flows southward and mixes with warm (9°C) North Atlantic Water to form the relatively cold (2.5°C) and saline (35.03‰) Northeast Atlantic Deep Water (Pickard and Emery, 1982). Part of the Northeast Atlantic Deep Water flows into the eastern North Atlantic basin and the remainder flows westward and diverges at the southern margin of the Reykjanes Ridge: one part turns north and forms a cyclonic gyre around the Irminger Basin and the other flows northwestward into the southern Labrador Basin. The latter overflow water eventually joins the main body of Norwegian Sea Overflow Water consisting primarily of the relatively fresh (<34.93‰) and cold (<2.5°C) Denmark Strait Overflow Water off the southern tip of Greenland (Ivers, 1975). Then, this deep current circulates counterclockwise around the Labrador Basin and continues southward. The fast-flowing (9 to 18 cm s^{-1}) and contour-following deep-water layer at a depth from about 1,500m to more than 3,000m of the deep water-mass has been called the Western Boundary Undercurrent (Heezen et al., 1966; Stanley et al., 1981; Bulfinch et al., 1982). Below this water-mass, the Northwest Atlantic Bottom Water (1.0°C and 34.91‰), comprising mixtures of Denmark Strait Overflow Water, Labrador Sea Water and Northeast Atlantic Deep Water, flows southward into the western North Atlantic basin (Pickard and Emery, 1982).

1.2. PREVIOUS WORK

1.2.1. ECOLOGY OF COCCOLITHOPHORIDS

Coccolithophorids are photosynthetic algae which occur dominantly in the photic zone of the nearshore to open oceanic realms except polar regions characterized by year-around sea-ice cover. The flora plays a significant role as a primary producer in marine ecosystem together with diatoms and dinoflagellates. Most modern coccolithophorids species endure a relatively wide range of salinities. For instance, E. huxlevi has a salinity range of 45 ‰. to 16 ‰. (Hasle 1978). Okada and Honjo (1973) suggested that salinity is not a major controlling factor in the distribution of modern coccolithophorids. Instead, the temperature of the photic water has been considered an important factor in the distribution of coccolithophorids (McIntyre and Bé, 1967; McIntyre et al., 1970).

By studying both plankton samples and surface sediments from the Atlantic Ocean, McIntyre and Bé (1967) described the latitudinal distribution of coccolithophorids and showed that the floral diversity decreased toward higher latitudes. Study of modern Pacific coccolithophorids also suggested that the distribution of some coccolithophorid species is essentially latitudinal, showing a relatively good relationship with surface water temperatures (McIntyre et al., 1970). Okada and Honjo (1973) emphasized the importance of oceanic current pattern in the surface distribution of modern Pacific coccolithophorids. They indicated that some high-latitude areas (between 45°N and 50°N) of the Pacific Ocean are characterized by a low species diversity but a high standing crop, perhaps due to the Pacific Subarctic Current water which has a temperature range of about 10 to 19°C.

Distribution of modern coccolithophorids is complicated by a certain amount of seasonal variations. For instance, study of modern coccolithophorids at a weather station in the Labrador Sea (56°30N 51°00W) exhibited that Coccolithus pelagicus overwhelmed the floral standing crop during spring and summer, whereas Emiliania huxleyi dominated the standing crop during fall and winter (Okada and McIntyre, 1979). Dissolution of coccoliths after deposition further complicates the application of the biogeography of modern coccolithophorids to paleoenvironmental analysis. Because our present knowledge of seasonal variations in coccolithophorid standing crop and selective dissolution of coccoliths is incomplete, all paleoenvironmental interpretations inferred from coccolith assemblages should be considered as tentative. Further detailed discussions on the biogeography of coccolithophorids and the effect of dissolution on coccolith assemblages are presented in CHAPTER 6: 6.1.4. and 6.1.1., respectively.

1.2.2. PLEISTOCENE CLIMATIC CHANGES AND MILANKOVITCH CYCLES

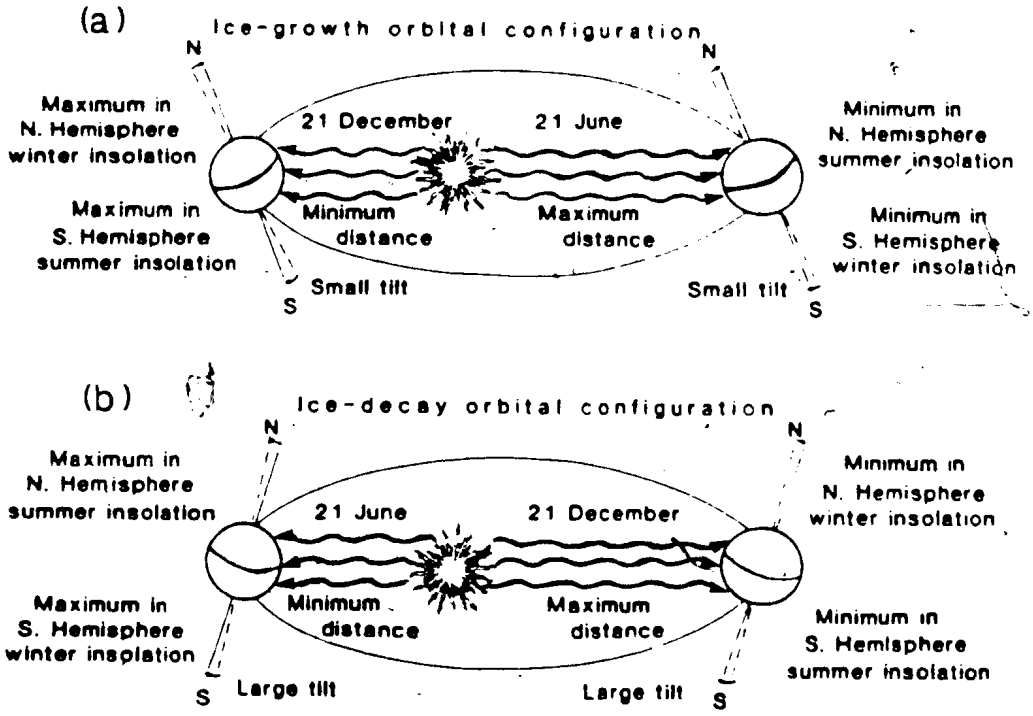
Ruddiman and McIntyre (1981a) described Milankovitch's (1941) postulate that summer insolation in the Northern Hemisphere, particularly at 65°N is critical to the growth and decay of Northern Hemisphere ice sheets. The amount of insolation at any given latitude and season is determined by three orbital parameters of the earth: the obliquity of the earth's axis, the precession of the equinoxes, and the eccentricity of the earth's orbit (op. cit.). The obliquity of the earth's axis is represented by the angle between the equatorial and ecliptic planes of the earth. It is now 23.5°; however, it varies from 22.1 to 24.5° with a period of about 41,000 years (Vernekar, 1972). The precession is the change in the orientation of the earth's axis which is characterized by a slow circular motion about a line that is perpendicular to the ecliptic plane, which takes about

21,000 years to complete one cycle (Vernekar, 1972). The eccentricity is measured by the ratio of the focal distance (distance between two foci) to the longest diameter of the elliptical orbit of the earth. It varies between a value near zero and about 0.006 with a period of about 93,000 years to complete one cycle (Vernekar, 1972). The cycles of the earth's orbital parameters are commonly called "Milankovitch cycles".

Orbital configuration of the earth in relation to the sun is illustrated in Fig.1.3. Northern Hemisphere summer insolation is at a minimum when the earth is at a maximum distance (aphelion precessional position) in the eccentric orbit and the axis of the earth is minimally tilted (Fig.1.3a). Summer insolation in the Northern Hemisphere is at a maximum when the earth is at a minimum distance (perihelion precessional position) and the axis of the earth is maximally tilted (Fig.1.3b). Aphelion and perihelion precessional positions are designated as "ice-growth" and "ice-decay" orbital configurations, respectively (Ruddiman and McIntyre, 1981a). North of 65°N, the obliquity of the earth's axis is more important in minimizing or maximizing Northern Hemisphere summer insolation, whereas south of 65°N, the precessional position is more important (Milankovitch, 1941 in Ruddiman and McIntyre, 1981a).

The causal relationship between the Milankovitch orbital cycles and the Pleistocene climatic changes has been strongly supported by Hays et al. (1976) who showed that the periodicities of the three orbital parameters of the earth correspond to the frequencies of major glacial fluctuations during the Pleistocene. According to Hays et al. (1976), spectral analysis of the oxygen isotopic record and sea-surface temperature record from two deep-sea cores in the southern Indian Ocean produced three discrete peaks with frequencies of 23,000, 42,000 and about 100,000 years. They correlated the 42,000 year climatic cycle to the period of the obliquity of the earth's axis; the 23,000 year climatic cycle to the period of the precession; and the dominant, 100,000 year

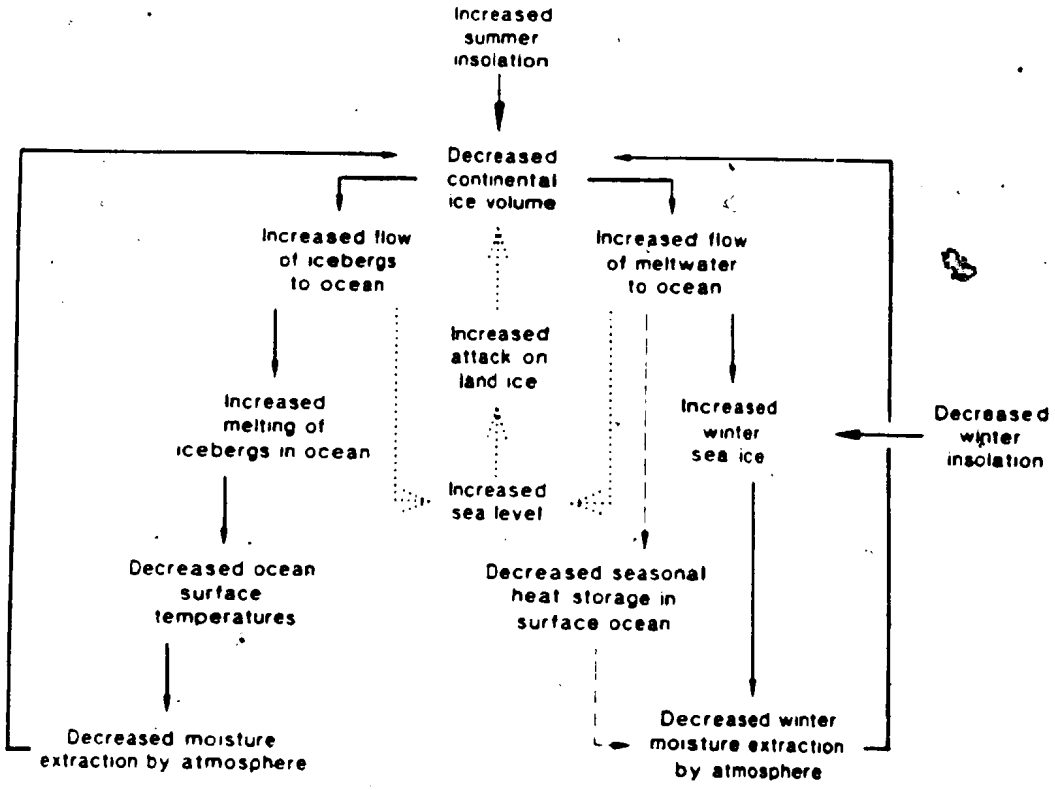
Fig. 1.3. Orbital configuratión of the earth in relation to the sun a) during glaciation and b) during deglaciation (after Ruddiman and McIntyre, 1981a).


(a)
Ice-growth orbital configuration
N
N
Maximum in
N. Hemisphere
winter insolation
21 December
21 June
Minimum in
N. Hemisphere
summer insolation
Maximum in
S. Hemisphere
summer insolation
Minimum
distance
Maximum
distance
Minimum in
S. Hemisphere
winter insolation
S
Small tilt
Small tilt
S
(b)
Ice-decay orbital configuration
N
N
Maximum in
N. Hemisphere
summer insolation
21 June
21 December
Minimum in
N. Hemisphere
winter insolation
Maximum in
S. Hemisphere
winter insolation
Minimum
distance
Maximum
distance
Minimum in
S. Hemisphere
summer insolation
S
Large tilt
Large tilt
S

climatic cycle to the period of the eccentricity. Because the eccentricity orbital parameter is known to play a minor role in changing the insolation of the earth compared to the other orbital parameters, Hays et al. (1976) assumed that the dominant 100,000 year climatic cycle is a nonlinear response to orbital forcing.

Data from North Atlantic cores suggested that during the late Pliocene and early Pleistocene Matuyama magnetic chron (2.47 to about 0.735 Ma), the spectral peaks of sea-surface temperature and oxygen isotopic record occur dominantly at a period of 41,000 years, whereas during the late Pleistocene Brunhes magnetic chron (0.735 to 0 Ma), the dominant spectral powers in climatic record occur at a period near 100,000 years (Ruddiman and McIntyre, 1984; Ruddiman, Raymo, and McIntyre, 1986; Ruddiman, Backman et al., 1987). Data from Arctic Ocean cores also indicated that the dominant ice-volume cycles during the last 0.9 m.y. occur at a period of 100,000 years (Williams et al., 1981). Ruddiman and McIntyre (1981a) suggested that the dominant 100,000 year ice-volume cycles during the late Pleistocene are the amplified signals of the 23,000 year precessional cycle resulting from the rapid termination of Northern Hemisphere ice sheets, particularly the Laurentide Ice Sheet in relation to maximum summer insolation when the ice sheets extended most southerly. The rapid deglaciation (about 10,000 years in duration) of Northern Hemisphere ice sheets was explained by means of oceanic feedback loops which show the relationship between insolation changes, ice-berg calving, and sea-level changes (Fig.1.4). However, the fundamental cause of the abrupt shift in dominant periodicity of ice volume and surface ocean response during the middle Pleistocene remains unexplained (Ruddiman, Backman et al., 1987).

Fig. 1.4. Oceanic feedback loops, showing interrelationship between insolation changes, ice-berg calving, and sea-level changes (after Ruddiman and McIntyre, 1981a).


Increased summer insolation
Decreased continental ice volume
Increased flow of icebergs to ocean
Increased flow of meltwater to ocean
Increased attack on land ice
Increased melting of icebergs in ocean
Increased winter sea ice
Decreased winter insolation
Increased sea level
Decreased ocean surface temperatures
Decreased seasonal heat storage in surface ocean
Decreased moisture extraction by atmosphere
Decreased winter moisture extraction by atmosphere

1.2.3. PLEISTOCENE PALEOCLIMATIC AND PALEOCEANOGRAPHIC HISTORY OF THE LABRADOR SEA

CLIMAP(1976) and Denton and Hughes(1983) proposed models which show permanent or year-around sea-ice cover in the Labrador Sea and Norwegian-Greenland Seas during the last maximum glaciation (around 18,000 years B.P.). Based on data from central subpolar North Atlantic cores, Ruddiman and McIntyre(1977) suggested that warm and saline North Atlantic Drift water was not able to penetrate the Labrador Sea during the last 0.8 m.y. except the extreme warmth of interglacial stages. Kellog (1977) also suggested that the glacial intervals during the last 450,000 years in the Norwegian-Greenland Seas are characterized by extensive year-around sea-ice cover.

On the contrary, data from central North Atlantic cores indicated that during an initial phase of glacial growth, the mid- and high-latitude North Atlantic Ocean (40° to 60°) was as warm as today's subpolar ocean despite minimum summer insolation (Ruddiman and McIntyre, 1979, 1981a; Ruddiman et al., 1980). During most of the period of ice-growth, the warm North Atlantic Ocean played an important role in transporting warm moisture via a narrow storm track along the Newfoundland coast into an ice-free Labrador Sea (Ruddiman et al., 1980). The cold but ice-free waters of the Labrador Sea contributed to the rapidly growing Laurentide Ice Sheet by providing moisture necessary for ice-sheet growth (Ruddiman et al., 1980).

Studies of the Labrador Sea and Baffin Bay cores also indicated that warm North Atlantic surface waters advected northward into the Labrador Sea and southern Baffin Bay during the early phases of glacial stages (Fillon and Duplessy, 1980; Fillon et al., 1981; Fillon 1985; Fillon and Aksu, 1985; Aksu, 1983; Mudie and Aksu, 1984; Aksu and Mudie, 1985; Aksu et al., in press). For

instance, the occurrence of subpolar planktonic foraminiferal assemblages in most of isotopic stage 2 in eastern Labrador Sea cores indicated that the eastern Labrador Sea was free of sea-ice in summer during that interval (Fillon and Duplessy, 1980). Based on subpolar planktonic foraminiferal abundance during isotopic stage 2 in Labrador Sea and Baffin Bay cores, Fillon and Aksu (1985) suggested the presence of a cyclonic surface water circulation pattern which is characterized by the advection of warm North Atlantic subpolar water along the west coast of Greenland into southern Baffin Bay and the southerly flow of polar surface water from northern Baffin Bay into the western Labrador Sea. The presence of subpolar planktonic foraminifera and Atlantic dinoflagellates in the early isotopic stages 2, 4, 6 and 8 in Baffin Bay cores (Mudie and Aksu, 1984) and in northwestern Labrador Sea cores (Aksu and Mudie, 1985) indicated strong advection of warm subpolar North Atlantic surface waters into northern Labrador Sea and southern Baffin Bay during the early phases of ice-growth. Blocking of the Arctic Island channels by ice, which prevented outflow of Arctic surface water into the North Atlantic, allowed northward advection of warm subpolar waters in the early phases of the glacial stages (Alam et al., 1983; Mudie and Aksu, 1984). These data are compatible with data from central North Atlantic cores which suggested an oceanic configuration providing a corridor of oceanic warmth along the intense thermal gradient between the cold land and warmer ocean during the early phases of Northern Hemisphere ice-sheet growth (Ruddiman and McIntyre, 1979, 1981a; Ruddiman et al., 1980). Data from ODP Sites 646 and 647 (Aksu et al., in press) support the oceanic configuration which prevailed during the early phases of ice-sheet growth; however, the lack of subpolar water-masses during the isotopic stage 6 in both sites conflicts with the presence of subpolar water-masses during the early to middle phases of the glacial stage in northwestern Labrador Sea cores (Aksu and Mudie, 1985).

Data from northwestern Labrador Sea cores showed that the later phases of

glacial stages are characterized by the decrease in subpolar planktonic foraminifera, radiolaria, dinoflagellates and pollen (Aksu and Mudie, 1985). The overall decline in the faunal and floral abundance during the late glacial stages indicated that the Arctic-Atlantic air front shifted southward and the Labrador Sea was covered with extensive year-around sea-ice which resulted in the removal of the warm West Greenland Current (op. cit.).

Planktonic foraminiferal data from Hole 647B showed periodic incursions of polar water-masses into the area of Site 647 during the isotopic stages 2, 4, 6, 12, 16 and 22 (Aksu et al., in press). Aksu et al. (op. cit.) suggested that the dominance of polar water-masses in the area during the glacial stages indicates the southward migration of the polar front and the increase in the influence of a cold current much like the present-day Labrador Current. During other glacial stages, the area of Site 647 was influenced by subpolar or transitional water-masses via the North Atlantic Drift; the western part of the Labrador Sea was dominated by polar water-masses via a cold Labrador Current (Aksu et al., in press).

Rapid transitions from glacial to interglacial stages were recorded in oxygen isotopic data from Labrador Sea cores (Aksu and Mudie, 1985; Aksu et al., in press). These data are compatible with data from central North Atlantic cores which suggested the rapid deglaciation of Northern Hemisphere ice-sheets in relation to orbitally-forced insolation changes (Ruddiman and McIntyre, 1981a). These glacial to interglacial transitions in the oxygen isotopic record from northwestern Labrador Sea cores are characterized by the decrease of planktonic foraminifera and radiolaria and the sharp increase of diatoms in total abundance (Aksu and Mudie, 1985). The high abundance of diatoms and low ratios of benthic to planktonic foraminifera (B/P) led the authors to suggest that the observed changes in faunal and floral abundance resulted from the presence of a low salinity surface layer maintained by both freshwater influx from the

melting of surrounding continental ice sheets and less saline Arctic water influx through the Arctic Island channels. Data from central North Atlantic cores also suggested the development of low salinity surface layer during the glacial to interglacial transitions (Ruddiman and McIntyre, 1981a). However, the Labrador Sea data differ from the North Atlantic data where sediments were virtually barren of planktonic microfossils. The microfossil barren zones in glacial to interglacial transitions in the central subpolar North Atlantic were attributed to the development of a strong basal pycnocline which inhibited primary productivity by preventing nutrient-rich water at depth from mixing with the surface water (Ruddiman and McIntyre, 1981a). In contrast, the high abundance of diatoms at glacial to interglacial transitions in the northwestern Labrador Sea was attributed to the infiltration of nutrient-rich subpolar North Atlantic surface waters into the Davis Strait (Aksu and Mudie, 1985).

Data from northwestern Labrador Sea cores suggested that during the isotopic stage 3, surface circulation of the Labrador Sea was similar to that of the present-day northern Baffin Bay, whereas during the isotopic stage 5, surface circulation was similar to that of the present-day Labrador Sea (Fillon, 1985). Planktonic foraminiferal assemblages from Site 646 indicated predominance of polar water-mass during interglacial stages 13, 19 and 21 which suggest the absence of the West Greenland Current in the area during interglacial stages; however, the early phases of interglacial stages 5, 7, 9, 11 and 17 are dominated by subpolar planktonic foraminifera which suggest northward advection of subpolar water-mass via the West Greenland Current (Aksu et al., in press).

Data from northwestern Labrador Sea cores showed that during the oxygen isotopic stage 1 to the upper part of stage 5, the ratio of B/P are characterized by cyclic variations: generally high during glacial stages and low during interglacial stages (Aksu and Mudie, 1985). During the oxygen isotopic stage 7, the ratios of B/P are constantly low, whereas the total abundance of planktonic

foraminifera greatly fluctuated: high in the upper and lowermost part of the stage and considerably low in the middle of the stage (op. cit.). These data led the authors to propose that variations in the total abundance of planktonic foraminifera reflect the biological productivity history superimposed on the dissolution cycles of the Labrador Sea area.

The results from the foregoing paleoenvironmental studies, which are critical to understanding the Pleistocene paleoclimatic and paleoceanographic trends in the Labrador Sea, can be summarized as follows:

i) During the early phases of several Pleistocene glacial stages, the Labrador Sea was ice-free and it played a major role in transporting moisture from the central North Atlantic into the central part of Laurentide, Innuitian and Greenland ice sheets via channelized storm tracks.

ii) During the late phases of glacial stages, southward shift of the Arctic-Atlantic air front caused year-around sea-ice cover in the Labrador Sea.

iii) During the transition from glacial to interglacial stages, a low salinity surface layer was developed in the northwestern Labrador Sea, which suppressed planktonic foraminiferal and radiolarian productivities.

iv) During the interglacial stages, the paleoclimatic and paleoceanographic conditions of the Labrador Sea were similar to the present-day climatic and oceanographic conditions.

1.2.4. LATE QUATERNARY COCCOLITH BIOSTRATIGRAPHY AND PALEOCEANOGRAPHY OF THE HIGH-LATITUDE NORTH ATLANTIC

Few biostratigraphic and paleoceanographic studies have been made of calcareous nannofossils from high-latitude North Atlantic sediments. Recently, studies of coccoliths from late Quaternary Labrador Sea sediments (Hudson 84-030-003 and 006) by Hearn (1986) and from late Quaternary Northeast Atlantic, Norwegian Sea and eastern Arctic sediments by Gard (1986, 1988) have been done.

Hearn (1986) identified a total of 9 coccolith species from sediments recovered in gravity and piston cores which penetrated into oxygen isotope stage 8 in 84-030-003 and penetrated into stage 5 in 84-030-006. The first appearance datum (FAD) of E. huxleyi was found to occur within the upper part of oxygen isotope stage 8 in 84-030-003 which is the site survey core of ODP Site 647 (Hearn, 1986). Hearn (1986) observed coccolith barren zones in the upper part of oxygen isotope stage 2, interstadial to glacial transition 3/2 and glacial to interglacial transition 6/5 in 84-030-003 and the upper parts of glacial stages 2 and 4 in 84-030-006. She attributed these barren zones to southward penetration of polar water-masses. Based on the relatively persistent occurrence of Gephyrocapsa oceanica in these two cores, Hearn(1986) inferred that Gulf Stream water contributed continuously to the Labrador Sea through the interval studied.

Gard (1986) observed the FAD of E. huxleyi and dominance reversal between Gephyrocapsa sp. and E. huxleyi within oxygen isotope stages 8 and 4, respectively in DSDP Hole 552A (56°N 25°W). She identified Gephyrocapsa sp. only at the genus level because of the difficulties of determining the flora at the species level. The dominance reversal between Gephyrocapsa sp. and E. huxleyi

was marked above oxygen isotope stage 4 in Norwegian Sea-Fram Strait cores (Gard, 1986). The discrepancy of the dominance reversal between DSDP Hole 552A and Norwegian-Fram Strait cores was attributed to either selective dissolution of E. huxleyi or time-transgressiveness of the reversal event between these two species (op cit.). To establish the biostratigraphy of Norwegian Sea-Fram Strait areas, Gard (1988) determined the quantitative content of coccoliths in sediments under light microscope. She observed high coccolith abundance intervals in oxygen isotope stages 1, 5, 11, 12 and 13 and inferred that the Norwegian-West Spitsbergen current system was established during these intervals, with possible inflow of North Atlantic water.

These studies above mentioned have demonstrated a significant potential of coccoliths for further improving the resolution of Late Cenozoic paleoceanography of the high-latitude North Atlantic. The aim of the present study is formulated in that perspective.

1.3. SCIENTIFIC OBJECTIVES

The primary scientific objectives of this study are:

i) to identify and determine the biostratigraphic distribution of Pleistocene nannofossil species in Site 647;

ii) to explore the biogenic carbonate productivity history of the southern Labrador Sea by examining the floral abundance variations in relation to glacial and interglacial fluctuations;

iii) to reconstruct the surface water-mass history of the area, primarily based on the floral assemblages; and

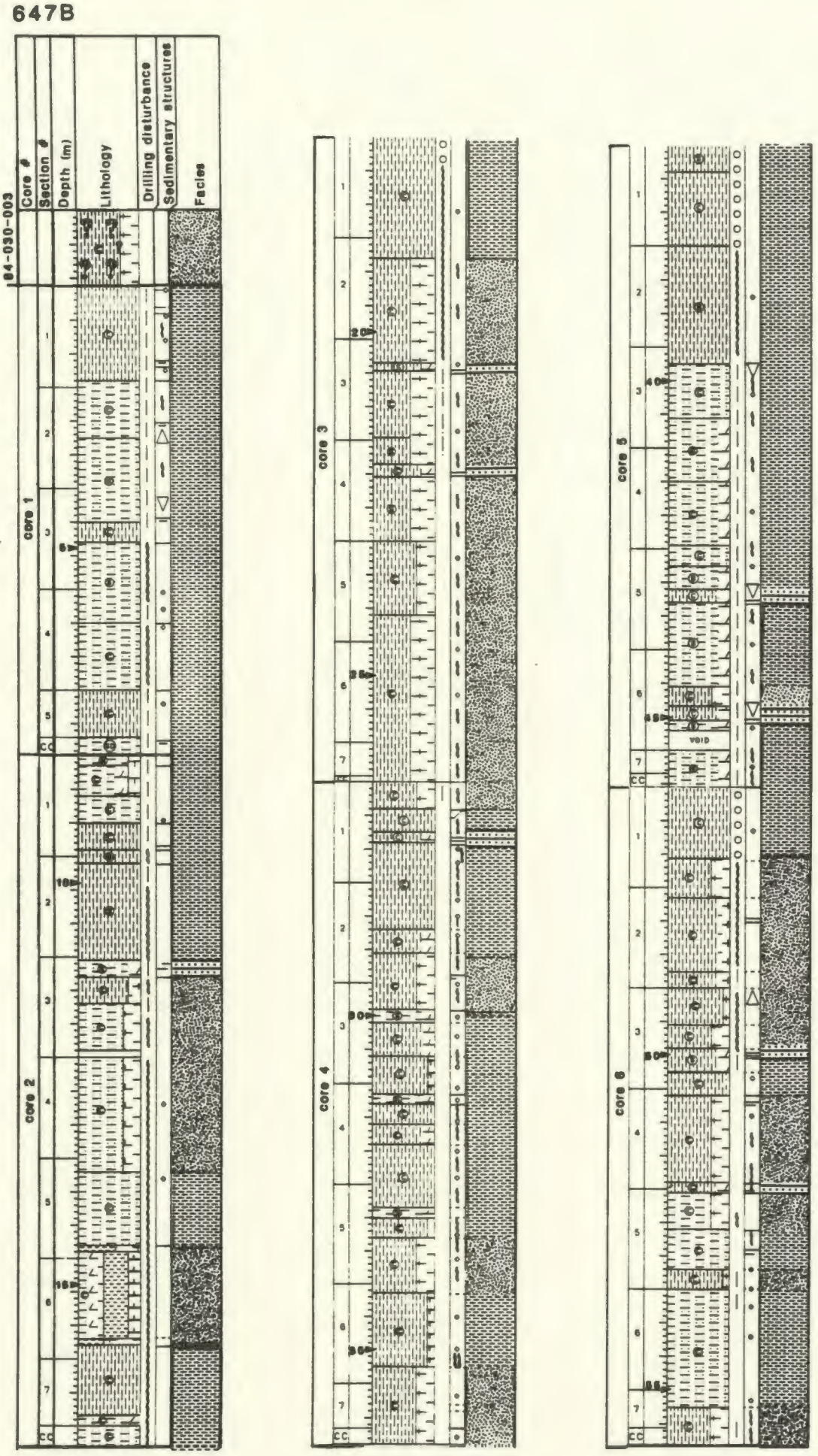
iv) to infer the surface current interactions in the area, particularly between the Labrador Current and the North Atlantic Drift in comparison with the previously established regional paleoceanographic trends in the Labrador Sea.

CHAPTER 2

MATERIAL AND TECHNIQUES

Sediments used in this study were collected during ODP Leg 105, Hole 647B using a hydraulic piston corer (Srivastava, Arthur, Clement et al., 1987). The core recovery at Hole 647B is illustrated in Table 2.1. The first six cores (647B-1H to 6H) were sampled at approximately 20cm interval. Initial results of the foraminiferal and stable isotopic record indicated that the uppermost part ca. 1.1m of 647B-1H was missing (Aksu et al., in press). To replace the missing part of 647B-1H, the upper part of the site survey core Hudson 84-030-003G (gravity core) was also subsampled. Thus, a total of 242 samples (236 from Hole 647B and 6 from Hudson 84-030-003G) was taken at about 20cm interval for coccolith studies. The oxygen isotopic record (Aksu et al., in press) and the paleomagnetic data (Srivastava, Arthur, Clement et al., 1987) indicated that 20cm sampling interval represent ca. 4,400 years of temporal resolution in Hole 647B.

One to 2 grams of sediment samples were disaggregated in 1% calgon solution and were sieved through a 20 μm sieve. The fine fractions were collected in a 20 ml vial and were put in suspension. After about six hours, the smaller clay particles still in suspension were removed from the top by pipette. This procedure was repeated until the liquid became clear. A small amount of sample was mounted on the SEM stub with a drop of acetone. Dry samples were gold coated in vacuum and coccoliths were identified and counted directly on the SEM (Hitachi-530) set at X5,000 magnification. At least 200 specimens were counted in each sample; however, in cases where the total abundance of coccoliths were considerably low, counting was interrupted on the 100th frame even though the number of counted specimens is far below 200. The total


647B
84-030-003
Core #
Section #
Depth (m)
Lithology
Drilling disturbance
Sedimentary structures
Facies
core 1
core 2
core 3
core 4
core 5
core 6
VOID
CC

abundance of coccoliths in each sample was determined by "the number of coccoliths" in 100 SEM frames at X5,000 magnification. Samples containing less than 5 specimens in the total abundance were considered barren. For quantitative paleoenvironmental analysis, each floral count was converted into percentile of the total count.

For quantitative analysis of the coccolith census data, multivariate analyses (cluster and factor analyses) were used. Cluster analysis was used to group the samples or species according to the following steps:

i) Similarities between the individual cases (Q-mode) or between the individual variables (R-mode) were computed.

ii) The nearest clusters were combined to form a new cluster.

iii) Similarities between the existing clusters and the new cluster were computed.

iv) Steps ii) iii) were repeated until all cases or all variables had been combined in one cluster.

To measure the similarity between cases (Q-mode), the Squared Euclidean distance was calculated. The distance between any pair of cases x and y is the sum of the squared differences between the values of the clustering cases (SPSS-X User's Guide, 1988). To measure the similarity between variables (R-mode), the angle of separation between variable vectors (the cosine coefficient) was used (Imbrie and Purdy, 1962). Ward's method and Average Linkage Between Groups method were used for Q-mode and R-mode cluster formation, respectively.

Factor analysis was used to extract underlying paleoenvironmental factors controlling the floral assemblages. Principal component analysis was chosen as the factor extraction technique in this study. Orthogonal varimax rotation was used to facilitate the interpretation of the extracted factors.

Both cluster and factor analyses were performed with SPSS-X subprogram "cluster" and "factor", respectively on the VAX/VMS computing system at Memorial University of Newfoundland.

CHAPTER 3

SEDIMENTS

The description of the cored sediments from Hole 647B follows the ODP Leg 105 Shipboard Scientific Party's original core description (Srivastava, Arthur, Clement et al., 1987). Based on shipboard analyses of color, grain size, mineralogy, sedimentary structures and microfossils (op. cit.), the sediments are divided by the author into three lithofacies (Fig. 3.1):

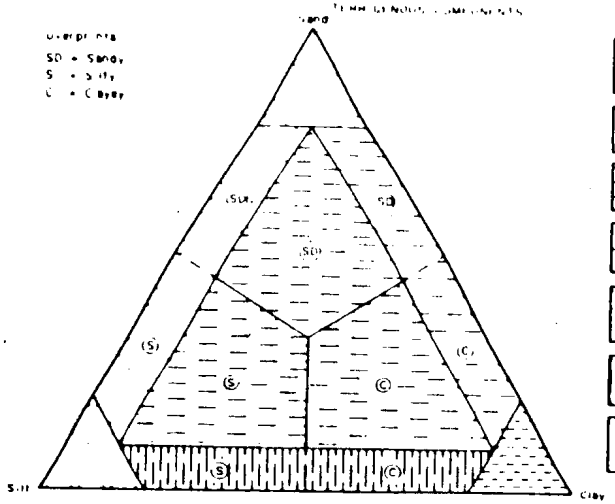
(1) Facies A

This facies consists primarily of gray silty clay, gray to brown clayey mud and gray to light brownish-gray clayey silt and silty mud with scattered ($<10\%$) gravels. These sediments contain $>75\%$ nonbiogenic components dominated by quartz, calcite, dolomite and clay minerals and $<15\%$ biogenic carbonates consisting mainly of coccoliths and foraminifera. Beds in this facies are generally structureless but exhibit color mottling and banding. Green glauconite-rich pockets observed in silty clays and clayey muds suggest the presence of bioturbation (Srivastava, Arthur, Clement et al., 1987). Pebble-sized clasts consist of granite, diorite, basalt, limestone, gneiss, quartzite and amphibolite (op. cit.).

Textural and mineralogical data suggest that this facies is the product of ice-rafting and hemipelagic sedimentation. Some of the clay-sized fractions are attributed to deposition from slow-moving nepheloid layers driven by weak bottom currents which are believed to have also contributed to build up Gloria Drift, just north of Site 647B (Srivastava, Arthur, Clement et al., 1987).

Fig. 3.1. Lithologic description and facies distribution of the cored sediments. Graphic symbols of lithology, drilling disturbance, and sedimentary structures are from Srivastava, Arthur, Clement et al. (1987). Facies determination of that portion of core 84-030-003 composited to the top of Hole 647B is from de Vernal and Hillaire-Marcel (1987b).

LEGEND



Overprints
SD = Sandy
S = Silty
C = Clayey

Sand
Silt
Clay
Muddy sand (SD)
Silty mud (S)
Clayey mud (C)
Silty clay (C)
Clayey silt (S)
Silty sand (SD)
Sandy silt (S)

BIOGENIC COMPONENTS
(not all city sediment/rock types)

A Carbonates

Nannofossils
Foraminifers
Nannofossil Foraminifer
Unspecified

B Silica

Diatoms
Radiolarians
Unspecified

Special symbols

(G) Glauconitic
(P) Pyrite

Soft sediments

Slightly disturbed
Moderately disturbed
Very disturbed
Soupy

Hard sediments

Slightly fractured
Moderately fractured
Highly fragmented
Drilling breccia

Primary structures

Microfaults
Macrofaults
Rounded pebbles and cobbles
Undulose bedding
Slump blocks or slide folds
Load casts
Scour
Large slide fold
Convolute and contorted bedding
Large burrow
Micro cross laminae (including combing ripples)
Cross stratification
Sharp contact
Gradational contact
Parallel laminae
Poorly defined laminae
Graded bedding (normal)
Upward fining sequence
Upward coarsening sequence
Bioturbation minor (< 30% surface area)
Bioturbation moderate (30% - 60% surface area)
Bioturbation strong (> 60% surface area)

Secondary structures

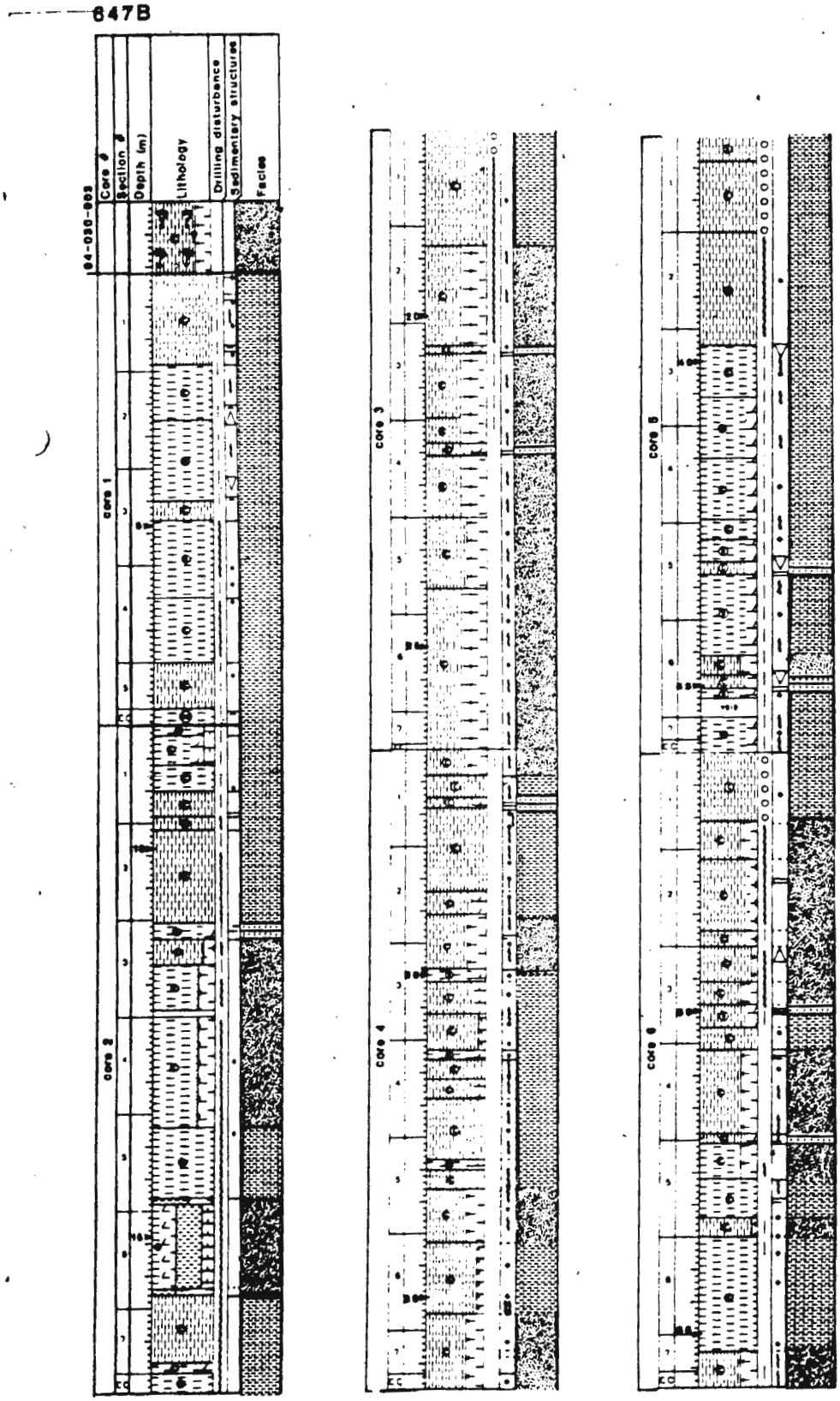
Concretions

Compositional symbols

Fossils in general (megafossils)
Shells (complete)
Shell fragments
Wood fragments

Lithofacies

Facies A
Facies B
Facies C


647B
Core #
Section #
Depth (m)
Lithology
Drilling disturbance
Sedimentary structures
Facies
core 1
core 2
core 3
core 4
core 5
core 6

(2) Facies B

This facies consists primarily of bioturbated gray to light brownish gray foraminifera-coccolith-rich silty clays. Beds are generally structureless except for local color banding. In some places, the tops of beds are sharp; the uppermost few centimeters contain abundant foraminifera and low coccoliths, which are interpreted as a result of nondeposition and bottom current winnowing, respectively (Srivastava, Arthur, Clement et al., 1987). The maximum biogenic carbonate content varies between 40 and 50%.

Textural and compositional data suggest that these sediments were deposited by hemipelagic sedimentation, probably during high biological productivity intervals, with relatively minor contributions from ice-rafting and bottom current sedimentation (op. cit.).

(3) Facies C

This facies consists primarily of laminated detrital carbonate silty clay or clayey silt beds, each about 20cm thick. A shipboard X-radiograph showed that beds usually comprise very fine sand and silt layers, each 1 to 3cm thick. The beds have sharp bases and the individual laminae show normal grading. Bioturbation is almost absent in this facies. The carbonate content is very high (up to 75%), and the calcite/dolomite ratio is approximately 1.5:1.0. Beds in this facies also exhibited sharp contacts with overlying and underlying beds of facies B.

These sediments are interpreted to have been deposited by turbidity currents, perhaps by overflows of channelized turbidity currents through NAMOC (Srivastava, Arthur, Clement et al., 1987).

CHAPTER 4

SYSTEMATIC TAXONOMY

Because coccolithophorids exhibit the faunal characteristic (e.g., the possession of flagella and phagotrophic nutrition) and the floral characteristic (e.g., photosynthetic nutrition), they have been claimed by both zoologists and botanists. Accordingly, coccoliths have been assigned by botanists to Order Coccolithophorales, Class Coccolithophyceae, Phylum (or Division) Chrysophyta and by zoologists to Order Coccolithophorida, Class Flagellata, Phylum Protozoa (Loeblich and Tappan, 1966; Hay, 1977). Botanist's assignments are used in this study. The classification at the level of family and genus used in this study follows that of Hay (1977). Species determination is based on various references which are listed in the synonyms of each species. It should be noted that not all references cited in the taxonomic section are listed in the reference but they can be found in Loeblich and Tappan (1966-1973).

Phylum Chrysophyta

Class Coccolithophyceae Rothmaler, 1951

Order Coccolithophorales Schiller, 1926

Family Coccolithaceae Kamptner, 1928

Genus Coccolithus Schwartz, 1894

Type species : Coccolithus pelagicus (Wallich, 1877) Schiller, 1930

Coccólithus pelagicus (Wallich, 1877) Schiller, 1930

Pl. 1, figs. 1,2

Synonyms : McIntyre et al., 1967, p. 11, pl. 4, figs. a, b; Black, 1968, p. 796, pl. 143, figs. 1, 2; Bartolini, 1970, p. 132, pl. 1, figs. 2-7

Remarks : The specimens identified as C. pelagicus in this study resemble that

described in McIntyre et al. (1967, p.11). However, the edge of the outer elements in distal view is characterized by straight line instead of counter-clockwise curvature indicated by the authors (op. cit.). The counter-clockwise curvature might be ascribed to the rounded-off edge as pointed out by Bartolini (1970). In general, this species is considerably larger than the other species, mostly ranging from 8 to 10 μm in size.

Genus Calcidiscus Kamptner, 1950

Type species : Calcidiscus leptoporus (Murray and Blackman, 1898) Loeblich and Tappan, 1978

Calcidiscus leptoporus (Murray and Blackman, 1898) Loeblich and Tappan, 1978

Pl. 1, figs. 4-6

Synonyms : McIntyre and Bé, 1967, p. 569, pl 7, figs. a-c; McIntyre et al., 1967, p. 10, pl. 5, figs. a-d; McIntyre et al., 1970. p. 725, fig. 5- a, b.

Remarks : Three varieties have been defined primarily based on the number of elements and the size of the species (McIntyre et al., 1967). Varieties A, B and C are characterized by 6 to 8.7 μm size - 40 elements, 4 to 6.5 μm size - 30 elements and 4.1 to 7.5 μm size - 20 elements, respectively. A new species name, C. macintyrei has been assigned to variety A (Bukry and Bramlette, 1969). Although varieties B and C can be detected based on the criteria mentioned above, clear separation between the two was not attempted in this study.

Genus Umbilicosphaera Lohmann, 1902

Type species : Umbilicosphaera mirabilis Lohmann, 1902

Umbilicosphaera mirabilis Lohmann, 1902

Pl. 1, fig. 3

Synonyms : Black and Barnes, 1961, p. 140, pl. 25, figs. 4, 5; McIntyre et al., 1967, p. 13, pl. 2, figs. c, d; McIntyre and Bé, 1967, p. 572, pl. 12, fig. a; Bartolini, 1970, p. 146, pl. 8, figs. 4-9.

Remarks: This species has a distal shield consisting of a firmly interlocked inner part and a sinistrally overgrown outer part of the elements. The center of the distal shield is characterized by a crater-like depression. In some case, the outer part of the distal shield is partially or completely lost. However, this species was identified by the unique appearance of the inner part of the distal shield and a crater-like depression in the center. McIntyre and Bé (1967) distinguished warm and cord water forms based on the overgrown shape of the distal shield. Although separation was not attempted in this study, most specimens are closer to cold water forms.

Family Gephyrocapsaceae Black, 1971

Genus Gephyrocapsa Kamptner, 1943

Type species : Gephyrocapsa oceanica Kamptner, 1943

Gephyrocapsa oceanica Kamptner, 1943

Pl. 1, fig. 7

Synonyms : Black and Barnes, 1961, p. 143, pl. 25, figs. 1, 2; McIntyre et al., 1967, p. 12, pl. 1, figs. a, b; Hay et al., 1967, pls, 12, 13, figs. 5, 6; Gartner, 1977, p. 18, pl. 3, figs. 7, 8

Remarks : The position of a bridge has been used as a diagnostic feature for this species (McIntyre et al., 1970). In case where the bridge was broken or missing, the specimens tend to be confused with Crenalithus doronicoides. The relative size of the central opening in this species has been related to the late Pleistocene climatic changes : small opening to cold climatic interval and larger opening to

warm climatic interval (Gartner, 1972, 1977). Gartner (1988) also suggested that "large G. oceanica" (>3 μm in maximum dimension) tends to be prosperous in warm (>27°C) water of moderate to low nutrient levels.

Gephyrocapsa caribbeanica Boudreaux and Hay, in Hay et al., 1967
Pl. 1, figs. 8,9
Synonyms : Hay et al., 1967, p. 447, pls. 12, 13, figs. 1-4; McIntyre et al., 1970, fig. 5, d; Samtleben, 1980, p. 124, figs. 9-14; Steinmetz and Stradner, 1984, pl. 1, figs. 2-4.

Remarks : This species has been considered to be the ancestor of G. oceanica (Boudreaux and Hay in Hay et al., 1967), but can be distinguished from G. oceanica primarily based on the bridge arching closely to the major axis and the central area which is partly or completely plugged with extended elements of a central tube.

Gephyrocapsa aperta Kamptner, 1963
Pl.1, figs. 10-12
Synonyms : Gartner, 1977, p. 18, pl. 3, figs. 5, 6; Samtleben, 1980, p. 123, figs. 7-18

Remarks: Very little description has been done of this species since it was first reported from the late Pleistocene sediments by Kamptner (1963). This species is a small (~1.5 to 2.5 μm) circular to elliptical placolith. The rim of the distal shield is considerably thin, whereas the central opening of the shield is relatively large. In some case, the bridge is highly arched subparalleling to the major axis. Samtleben (1980) illustrated excellent photographs of the specimens from the Atlantic. Geitzenauer (1971) reported that this species disappeared at the base of E. huxlevi Zone in the subantarctic Pacific Ocean. However, in this study area,

the species is found in high abundances above the FAD of E. huxleyi. G. aperta belongs to "small Gephyrocapsa" group of Gartner (1988). However, it should be noted that the "small Gephyrocapsa group" comprises several species because the group name was designated by lumping all the small specimens (<3 μm in maximum dimension) of the genus Gephyrocapsa under light microscope (Gartner, 1988).

Gephyrocapsa muellerae Breheret, 1978

Pl. 2, fig. 1

Synonyms : Samtleben, 1980, p. 124, figs. 6-8, p. 127, figs. 1-4

Remarks: This species has an abnormally thick bridge consisting of two opposed overlapping spines. Roth and Coulbourn (1982) incorporated G. muellerae into G. caribbeanica due to interspecific variation between the two species. However, this species is described separately in this study because of the unique appearance of the bridge.

Gephyrocapsa rota Samtleben, 1980

Pl. 2, fig. 2

Synonyms : Samtleben, 1980, p. 123, figs. 19-24

Remarks : This species closely resembles G. protohuxleyi, particularly the warm water form. However, relatively thick bridge subparalleling to the minor axis of the central opening was used as a diagnostic feature in identification.

Gephyrocapsa protohuxleyi McIntyre, 1970

Pl. 2, fig. 3

Synonyms : McIntyre, 1970, p. 188, fig. 1, b, d, fig.; Gartner, 1977, p. 18, pl. 3, figs. 2, 3

Remarks : Two ecologic varieties have been described : cold water form characterized by long and thin "finger-like elements" in the distal shield and warm water form characterized by shorter and thicker elements (McIntyre, 1970). In addition, the bridge of cold water form is thinner and more highly arched obliquely across the major axis than that of warm water form. The specimens observed in this study are closer to the cold water form. McIntyre (1970) also suggested that G. protohuxleyi is a "phyletic link" between the Gephyrocapsa complex and E. huxleyi.

Genus Crenalithus Roth, 1973

Type species : Crenalithus doronicoides (Black and Barnes, 1961) Roth, 1973

Crenalithus doronicoides (Black and Barnes, 1961) Roth, 1973

Pl. 3, figs. 1-4

Synonyms : Roth, 1973, p. 731, pl. 3, fig. 3; Steinmetz and Stradner, 1984, p. 701, pl. 2, figs. 3, 4

Remarks : This species is distinguished from G. caribbeanica and G. oceanica primarily based on the lack of a bridge in the central opening. The specimens observed in this study mostly ranges from 4 to 5.5μm in length. Some specimens classified into this species bear a few slits between the elements of the distal shield, which makes it difficult to distinguish the species from P. lacunosa. The specimens with a few slits in the distal shield might be considered as a phyletic link between C. doronicoides and P. lacunosa. Sachs and Skinner (1973) suggested phyletic relationships between six species including C. doronicoides, P. lacunosa and G. caribbeanica. However, more study of the materials from other areas is required to substantiate the possibility of the phyletic links between these species.

Genus Pseudoemiliania Gartner, 1969

Type species : Pseudoemiliania lacunosa (Kamptner, 1963) Gartner, 1969

Pseudoemiliania lacunosa (Kamptner, 1963) Gartner, 1969

Pl. 3, figs. 5-7

Synonyms : Gartner, 1977, p. 20, pl. 4, figs. 3, 4; Takayama and Sato, 1987, p. 702, pl. 8, fig. 2

Remarks: This species is a circular or elliptical placolith with slits between the elements of the distal shield. The slits are regularly or irregularly distributed. The central opening of the specimens is circular or elliptical. The maximum length of the specimens ranges from 4 to 7.5μm.

Genus Emiliania Hay and Mohler, in Hay et al., 1967

Type species : Emiliania huxleyi (Lohmann, 1902) Hay and Mohler, in Hay et al., 1967

Emiliania huxleyi (Lohmann, 1902) Hay and Mohler, in Hay et al., 1967

Pl. 2, figs. 4-6

Synonyms : Hay et al., 1967, p. 447, pls. 10, 11, figs. 1, 2; Boudreaux and Hay, 1969, p. 262, pl. 2, figs. 10-12

Remarks : Two ecologic varieties have been described by McIntyre and Bé. The warm water variety is characterized by 'T' shaped elements of both the distal and proximal shields, whereas the cold water variety is characterized by 'T' shaped elements of the distal shield and by flattened elements of the proximal shield. The specimens observed in this study resemble the cold water variety; however, the distal shield elements of the specimens are almost 'I' shaped or

pointed toward the margin, perhaps due to partial dissolution . McIntyre and McIntyre (1971) reported that highly dissolved specimens of E. huxlevi are indistinguishable from highly dissolved specimens of G. oceanica. Although the majority of specimens show indication of strong dissolution, such an extreme case is rarely observed in this study.

Family Pontosphaeraceae Lemmermann, 1908

Genus Pontosphaera Lohmann, 1902

Type species : Pontosphaera syracusana Lohmann, 1902

Pontosphaera alboranensis Bartolini, 1970

Pl. 2, fig. 8

Synonyms : Hay et al., 1967, pls. 10, 11, fig. 6; Bartolini, 1970, p. 148, pl. 6, figs. 6, 7; Steinmetz and Stradner, 1984, pl. 7 fig. 1

Remarks: This species is a large (12 to 15μm in maximum length) elliptical basket-shaped coccolith with numerous central perforations and a lamellar rim. The perforations (about 0.1μm in diameter) are arranged in radial rows almost to the margin of the distal shield. The lamellar rim, which is the margin of the distal shield, is stretched (clockwise) in a sigmoidal shape in distal view. This species closely resembles P. syracusana illustrated in Perch-Nielsen (1985, p. 499, fig. 53). Only the smoothness of the contact between shield and rim makes it possible to distinguish this species from P. syracusana. This species was extremely rare throughout the samples and was treated together with P. japonica in the quantitative analysis.

Pontosphaera discopora Schiller, 1925

Pl. 2, fig. 9

Synonyms : Black, 1968, p. 800, pl. 146, figs. 1, 2; Boudreaux and Hay, 1969, p. 271, pl. 6, figs. 1, 2; Perch-Nielsen, 1985, p. 499, fig. 53, 7-9

Remarks: This species is a large (10 to 11 μm in maximum length) elliptical basket shaped coccolith with a slightly concave proximal surface. The central area of the proximal surface is perforated by relatively large size pores (about 0.2 μm in diameter). The presence of relatively large pores is a diagnostic feature distinguishing from other species of Pontosphaera.

Pontosphaera japonica (Takayama, 1967) Nishida, 1977

Pl. 2, figs. 7-10

Synonyms : Bartolini, 1970, p. 148, pl. 3, figs. 1-3; Wang and Samtleben, 1983, pl. 2, fig. 10; Perch-Nielsen, 1985, p. 449, fig. 53, 10

Remarks: This species is a large (9 to 11 μm in maximum length) elliptical caneolith with a shallow proximal depression and a nearly flat distal surface. The central area of the proximal surface is perforated by numerous pores (about 0.1μm in diameter). The margin of the proximal surface is composed of various rod-shaped segments which are arranged almost perpendicular to the rim. The margin of the distal surface is often roughly striated in a parallel direction to the elliptical margin. Black (1968, pl. 154, figs. 4,5) illustrated the specimens which closely resemble P. japonica as Scyphosphaera species. According to Hay (1977), the genus Scyphosphaera is distinguished from the genus Pontosphaera by its larger and deeper basket shape. Considering the shallow basket shape of the specimens illustrated in Black (1968), it seems conceivable the author may have misidentified the specimens.

Genus Helicopontosphaera Hay and Mohler, 1967

Type species : Helicopontosphaera kamptneri Hay and Mohler, 1967

Helicopontosphaera kamptneri Hay and Mohler, 1967

Pl. 3, figs. 8,9

Synonyms : Black and Barnes, 1961, p. 139, pls. 22,23; McIntyre et al., 1967, p. 12-13, pl. 6, figs. a,b; Hay et al., 1967, p. 448, pls. 10,11, fig. 5; Boudreaux and Hay, 1969, p. 272, pl. 6, fig. 8; Steinmetz and Stradner, 1984, pl. 9, figs. 1-4.

Remarks: The center of the proximal surface consists of an elliptical shield with two elongated slits. In some specimens, a narrow open slit instead of two elongate slits is observed in proximal view, perhaps due to partial dissolution. Narrow radiating plates spiral the central shield in a clockwise direction to form a flaring expansion at the end. The distal surface is characterized by two central pores and an expanded wing. H. sellii is distinguished from H. kamptneri by the presence of an oblique bridge in distal surface.

Family Rhabdosphaeraceae Lemmermann, 1908

Genus Rhabdosphaera Haeckel, 1894

Type species : Rhabdosphaera clavigera Murray and Blackman, 1898

Rhabdosphaera clavigera Murray and Blackman, 1898

Pl. 3, figs. 10,11

Synonyms : McIntyre and Bé, 1967, p. 567, pl. 4, figs. a-c (as R. stylifera); Boudreaux and Hay, 1969, p. 266, pl. 4, figs. 6, 11; Bartolini, 1970, p. 142, pl. 6, figs. 8,9

Remarks: This species is a nail or mushroom-like cyrtolith composed of a circular or elliptical basal plate and a club-shaped appendix. The basal plate is concave proximally. The appendix comprises a bundle of elongated rhomboidal

calcite elements. McIntyre and Bé (1967) and Bartolini (1970) considered R. stylifera as being synonymous with R. clavigera. However, Boudreaux and Hay (1969) distinguished R. stylifera from R. clavigera primarily based on the shape of the basal plate. The authors (op cit.) ascribed the specimens with an elliptical basal plate to R. stylifera. The majority of the specimens observed in this study lack basal plate. Therefore, no attempt has been made in this study to distinguish the two species.

Family Syracosphaeraceae Lemmermann, 1908

Genus Syracosphaera Lohmann, 1902
Type species : Syracosphaera pulchra Lohmann, 1902

Syracosphaera pulchra Lohmann, 1902
Pl. 3, fig. 12
Synonyms : Black and Barnes, 1961, p. 139, pl. 19, figs. 1,2; Bartolini, 1970, p. 144, pl. 8, figs. 1-3; Perch-Nielsen, 1985, p. 523, fig. 73, 6-8

Remarks: This species is a basket-shaped caneolith with an elliptical, flat bottom in a distal side. The center of the distal surface is characterized by radial ribs. The radial ribs are composed of bundles of elongated calcite crystals which are to some extent overlapped at the inner and middle parts. Elongate perforations are developed along the middle part of the radial ribs. This species was extremely rare throughout the samples (<1%). Incomplete specimens were observed often as elliptical rings. In this study, these specimens were counted as S. pulchra.

Plate 1

Figs. 1, 2 *Coccolithus pelagicus* (Wallich) Schiller

1. distal view X6,000 (647B-1H-3, 60-66cm)
2. proximal view X6,000 (647B-1H-3, 60-66cm)

Fig. 3 *Umbilicosphaera mirabilis* Lohmann

distal view X13,000 (647B-5H-5, 40-45cm)

Figs. 4-6 *Calcidiscus leptoporus* (Murray and Blackman) Loeblich and Tappan

4. distal view X8,000 (647B-6H-6, 80-85cm)
5. distal view X10,000 (647B-4H-6, 140-145cm)
6. side view X13,000 (647B-3H-3, 20-25cm)

Fig. 7 *Gephyrocapsa oceanica* Kamptner

distal view X20,000 (647B-2H-4, 140-145cm)

Figs. 8, 9 *G. caribbeanica* Boudreaux and Hay

8. coccosphere X15,000 (647B-3H-5, 40-45cm)
9. distal view X20,000 (647B-2H-3, 100-106cm)

Figs. 10-12 *G. aperta* Kamptner

10. side view X25,000 (647B-4H-2, 40-45cm)
11. distal view X25,000 (647B-3H-2, 120-125cm)
12. proximal view X25,000 (647B-1H-4, 80-86cm)

Plate 1

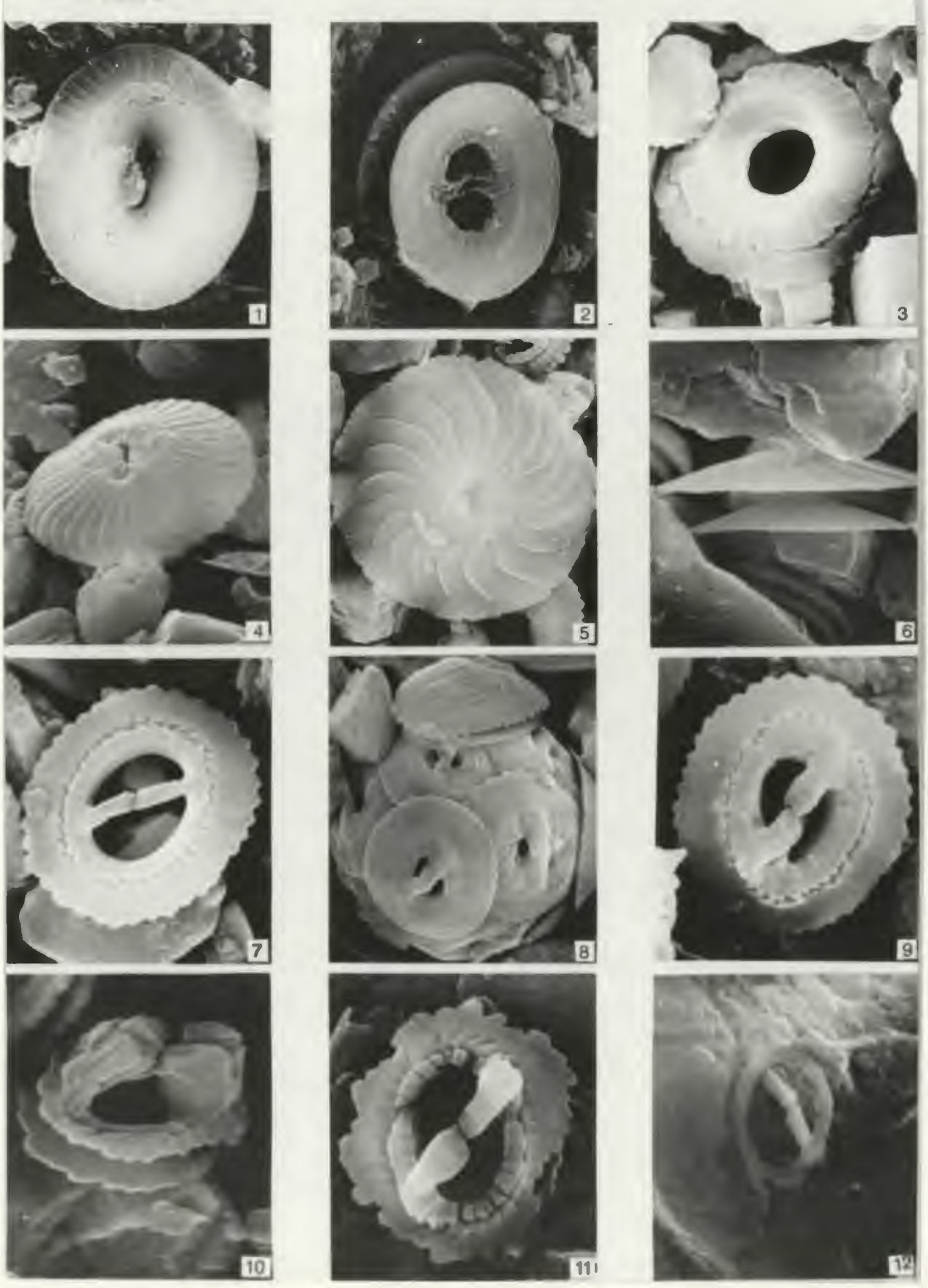


Plate 2

Fig. 1. *Gephyrocapsa muellerae* Breheret
distal view X20,000 (647B-2H-4, 100-105cm)

Fig. 2 *G. rota* Samtleben
distal view X15,000 (647B-4H-2, 140-145cm)

Fig. 3 *G. protohuxleyi* McIntyre
distal view X25,000 (647B-2H-4, 120-125cm)

Figs. 4-6 *Emiliania huxleyi* (Lohmann) Hay and Mohler
4. distal view X30,000 (647B-1H-2, 120-126cm)
5, 6. distal view X25,000 (84-030-003, 0cm)

Figs. 7-10 *Pontosphaera japonica* (Takayama) Nishida
7. proximal view X7,000 (647B-1H-4, 120-126cm)
8. proximal view X5,000 (647B-2H-2, 40-45cm)
9. proximal view X7,000 (647B-4H-7, 40-45cm)
10. distal view X8,000 (647B-2H-2, 60-66cm)

Fig. 11 *P. discopora* Schiller
proximal view X7,000 (647B-4H-5, 140-145cm)

Fig. 12 *P. alboranensis* Bartolini
proximal view X5,000 (647B-1H-4, 120-126cm)

Plate 2

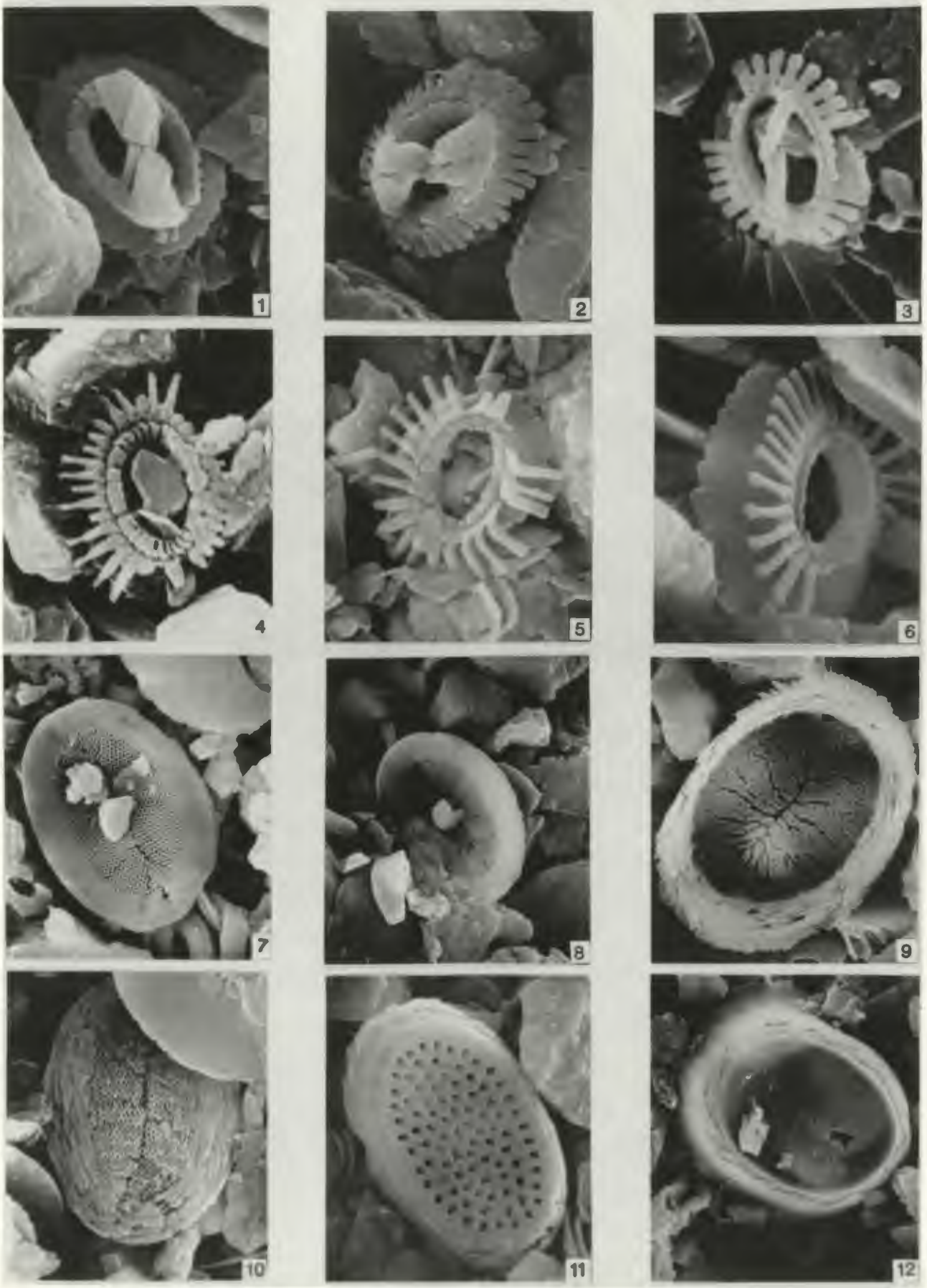


Plate 3

Figs. 1-4 Crenalithus doronicoides (Black and Barnes) Roth

1. distal view X11,000 (647B-5H-4, 120-125cm)
2. distal view X11,000 (647B-5H-4, 140-145cm)
3. distal view X15,000 (647B-5H-2, 20-25cm)
4. distal view X15,000 (647B-6H-4, 20-25cm)

Figs. 5-7 Pseudoemiliania lacunosa (Kamptner) Gartner

5. distal view X10,000 (647B-5H-4, 140-145cm)
6. distal view X11,000 (647B-3H-5, 120-126cm)
7. distal view X11,000 (647B-3H-7, 40-45cm)

Figs. 8,9 Helicopontosphaera kamptneri Hay and Mohler

8. proximal view X6,000 (647B-4H-5, 140-145cm)
9. proximal view X5,000 (647B-2H-2, 40-46cm)

Figs. 10,11 Rhabdosphaera clavigera Murray and Blackman

10. side view X10,000 (647B-6H-3, 40-45cm)
11. side view X10,000 (647B-4H-4, 40-45cm)

Fig. 12 Syracosphaera pulchra Lohmann

distal view X15,000 (647B-3H-3, 20-25cm)

Plate 3


1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CHAPTER 5

PLEISTOCENE COCCOLITH BIOSTRATIGRAPHY

5.1. INTRODUCTION

A large number of zonal schemes have been proposed mainly for lower latitudes (e.g., Hay et al., 1967; Gartner, 1969, 1977a; Martini, 1971; Bukry, 1978, 1975; Okada and Bukry, 1980). Among them, Martini's "Standard Zonation" and Bukry's zonation have been widely used and have proven to be useful for world wide correlation (Perch-Nielsen, 1986).

All calcareous nannofossil zonations now being used are based primarily on the concept of "the interval zone" which represents the stratigraphic interval between two datums.

There are several datums that can be used in Pleistocene sediments. Above the last appearance datum (LAD) of Discoaster brouweri at ca. 1.90 Ma (Berggren et al., 1984), the datums commonly used to devise the zonations of the Pleistocene are: first appearance datum (FAD) of G. caribbeanica, FAD of G. oceanica, LAD of C. macintyrei, LAD of H. sellii, LAD of P. lacunosa and FAD of E. huxleyi. Among these datums, the LAD of P. lacunosa and the FAD of E. huxleyi are considered the most reliable datums (Gartner, 1972). It is noticeable that the FADs of G. caribbeanica and G. oceanica are considered less important primarily due to interspecific variation between the two species in spite of their prolific occurrence throughout the Pleistocene.

Correlation of coccolith datums with the oxygen isotopic record from Pleistocene deep-sea sediments provided a useful guideline for stratigraphic

subdivision of the Pleistocene (Gartner, 1972; Gartner and Emiliani, 1976). The global synchroneity of the LAD of P. lacunosa and the FAD of E. huxleyi has been established by correlation with the oxygen isotopic record and paleomagnetic record of deep-sea cores from tropical, subtropical, transitional, and subpolar waters (Thierstein et al., 1977; Berggren et al., 1980, 1984). The LAD of P. lacunosa occurs in the middle of oxygen isotopic stage 12 at ca. 0.474 Ma and the FAD of E. huxleyi occurs within oxygen isotopic stage 8 at ca. 0.275 Ma (Berggren et al., 1984).

A few biostratigraphic studies have been made of Pleistocene coccoliths from the high latitude North Atlantic Ocean (e.g., Bukry, 1972; Perch-Nielsen, 1972; Gard, 1986, 1988; Takayama and Sato, 1987; Firth in Srivastava, Arthur, Clement et al, 1987). The zonations devised by Perch-Nielsen (1972, DSDP Leg 12) and Bukry (1972, DSDP Leg 12) are correlated with Martini's (1971) "Standard Zonation" (Table 5.1). Perch-Nielsen subdivided the Pleistocene into E. huxleyi Zone, G. oceanica Zone, Coccolithus doronicoides Zone and P. lacunosa Zone. On the other hand, Bukry combined the C. doronicoides Zone and P. lacunosa Zone of Perch-Nielsen to devise C. doronicoides Zone. Gard (1986, 1988) attempted to establish coccolith biozonation of Norwegian Sea-Fram Strait areas based on the total abundance of coccolith from sediments and the interrelationships between major component species e.g., E. huxleyi, C. pelagicus and Gephyrocapsa sp. by using light microscope. Takayama and Sato (1987, DSDP Leg 94) and Firth (1987, ODP Leg 105) employed Martini's (1971) "Standard Zonation" and detected NN21 (E. huxleyi Zone), NN20 (G. oceanica Zone) and NN19 (P. lacunosa Zone).

Definition of Perch-Nielsen and Bukry's zonations is considerably different from that of Martini's zonation. For instance, G. oceanica Zone of Bukry and Perch-Nielsen is defined by the interval from the FAD of G. oceanica to the FAD of E. huxleyi, whereas Martini's G. oceanica Zone is defined by the interval

Table 5.1. Correlation of the high latitude North Atlantic calcareous nanofossil zonations with Martini's (1971) "Standard Zonation".

Datums	Perch-Nielsen, 1972 (Leg 12, DSDP)	Bukry, 1972 (Leg 12, DSDP)	Martini, 1971 "Standard Zonation"
	E. huxleyi Zone	*E. huxleyi* Zone	NN21 (*E. huxleyi* Zone)
FAD of *E. huxleyi*			NN20 (*G. oceanica* Zone)
LAD of *P. lacunosa*	*G. oceanica* Zone	*G. oceanica* Zone	
FAD of *G. oceanica*	*C. doronicoides* Zone	*C. doronicoides* Zone	NN19 (*P. lacunosa* Zone)
FAD of *C. doronicoides*	*P. lacunosa* Zone		
LAD of *D. brouweri*			

from the LAD of P. lacunosa to the FAD of E. huxleyi (Table 5.1). Similarly, P. lacunosa Zone of Perch-Nielsen is defined by the interval from the LAD of D. brouweri to the FAD of C. doronicoides; however, Martini's P. lacunosa Zone is defined by the interval from the LAD of D. brouweri to the LAD of P. lacunosa (Table 5.1).

5.2. BIOSTRATIGRAPHIC ZONATION

Martini's (1971) "Standard Zonation" is employed in this study primarily because the FAD of E. huxleyi and the LAD of P. lacunosa have proven to be the most reliable and globally synchronous datums in the Pleistocene (Gartner, 1972; Thierstein et al., 1977; Berggren et al., 1980, 1984).

Emiliania huxleyi Zone (NN 21)

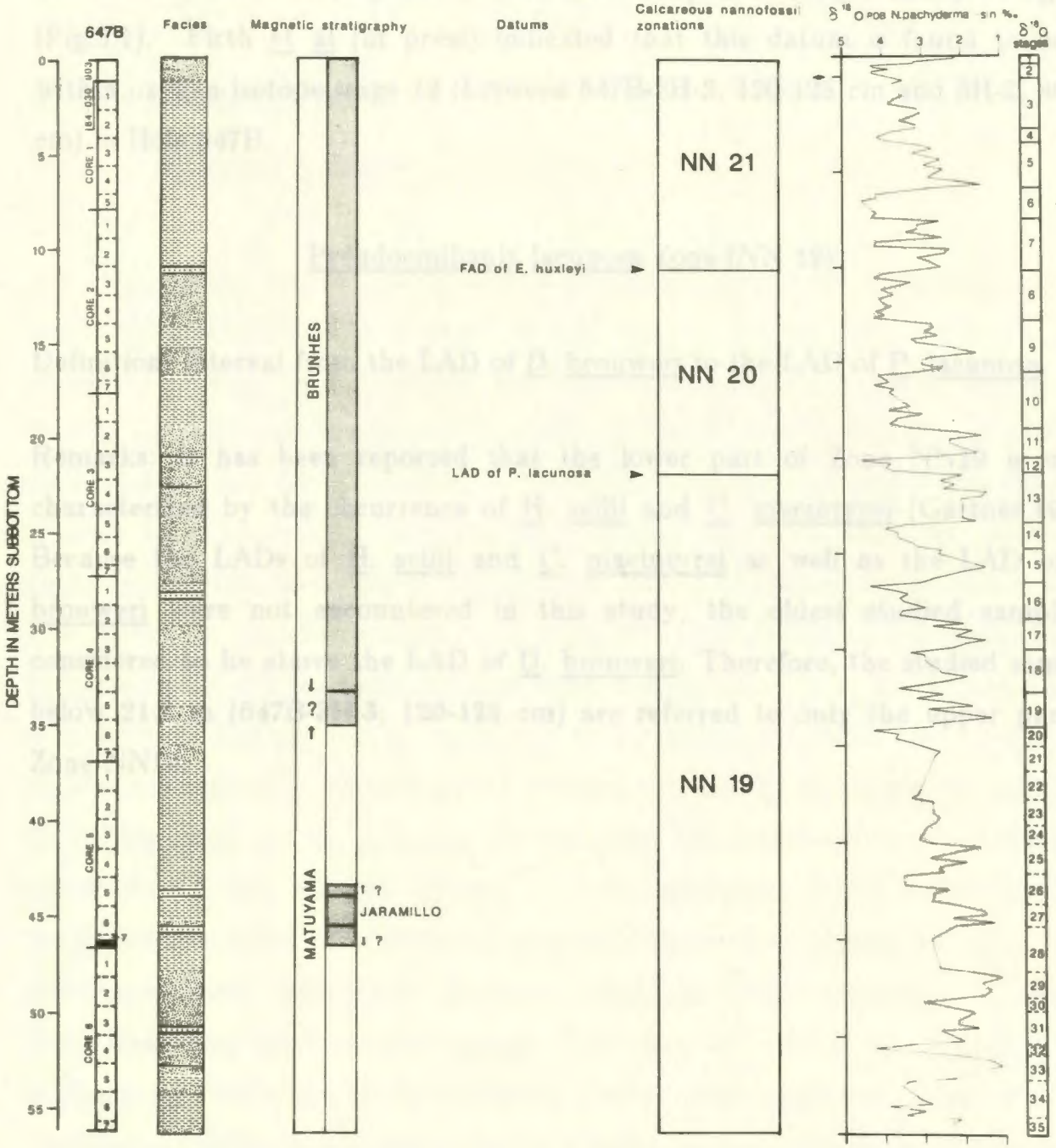
Definition : Interval from the FAD of E. huxleyi to the present.

Remarks : In this study, the FAD of E. huxleyi is found at 11.1m (647B-2H-3, 19-25 cm) which corresponds to the oxygen isotope stage transition 8/7 (Fig.5.1). The datum observed in this study is slightly younger than the global datum which occurs within oxygen isotopic stage 8 at ca. 0.275 Ma (Berggren et al., 1984). The previous nannofossil studies of Site 647 indicated that the FAD of E. huxleyi occurs within oxygen isotope stage 7 (between 647B-1H-7, 114-116 cm and 1H-6, 130-132 cm) in Hole 647B (Firth et al, in press) and within the upper part of oxygen isotope stage 8 in the site survey core 84-030-003 (Hearn, 1986).

Gephyrocapsa oceanica Zone (NN 20)

Definition: Interval from the LAD of P. lacunosa to the FAD of E. huxleyi.

Fig. 5.1. Calcareous nannofossil datums and zonations in Hole 647B. Magnetic stratigraphy and oxygen isotopic stratigraphy are from Srivastava, Arthur, Clement *et al.* (1987) and Aksu *et al.* (in press), respectively.


647B
Facies
Magnetic stratigraphy
Datums
Calcareous nannofossil zonations
δ18O PDB N.pachyderma s in ‰
δ18O stages
DEPTH IN METERS SUBBOTTOM
BRUNHES
MATUYAMA
JARAMILLO
FAD of E. huxleyi
LAD of P. lacunosa
NN 21
NN 20
NN 19

Remarks: In this study, the LAD of P. lacunosa occurs at 21.8m (647B-3H-3, 120-125 cm) which corresponds to the lowermost part of oxygen isotopic stage 12 (Fig.5.1). Firth et al (in press) indicated that this datum is found to occur within oxygen isotope stage 12 (between 647B-3H-3, 120-125 cm and 3H-2, 80-85 cm) in Hole 647B.

Pseudoemiliania lacunosa Zone (NN 19)

Definition: Interval from the LAD of D. brouweri to the LAD of P. lacunosa.

Remarks: It has been reported that the lower part of Zone NN19 is often characterized by the occurrence of H. sellii and C. macintyrei (Gartner,1977). Because the LADs of H. sellii and C. macintyrei as well as the LAD of D. brouweri were not encountered in this study, the oldest studied sample is considered to lie above the LAD of D. brouweri. Therefore, the studied samples below 21.8 m (647B-3H-3, 120-125 cm) are referred to only the upper part of Zone NN19.

CHAPTER 6

PALEOECOLOGY

6.1. INTRODUCTION

6.1.1. PRESERVATION

The effects of calcium carbonate dissolution on the species composition of coccolith assemblages have been studied in the Atlantic by McIntyre and McIntyre (1971), Berger (1973), and Schneidermann (1973, 1977) and in the Pacific by Roth and Berger (1975) and Roth and Coulbourn (1982). According to McIntyre and McIntyre (1971), the holococcoliths and caneoliths (basket-shaped heterococcoliths) are the first to be dissolved and the placoliths (heterococcoliths consisting of two circular shields connected by a central tube) and cyrtoliths (heterococcoliths consisting of a club-shaped basal plate and a long appendix) are the most resistant form to dissolution with depth. Among the placoliths, E. huxleyi and G. oceanica can be indistinguishable with progressive dissolution (op. cit.). Berger (1973) pointed out that C. leptopora, G. oceanica, G. caribbeanica and C. pelagicus are the most dissolution-resistant coccoliths in sediments of the Atlantic Ocean . Schneidermann (1973) subdivided the compensation zone of calcareous nannoplankton into mesolytic zone (only solution-resistant coccoliths present), oligolytic zone (removal of soluble coccoliths) and eolytic zone (initial dissolution of soluble coccoliths). The terminology used by Schneidermann (1973) was employed from Hsü and Anderson's (1970) description of five dissolution facies in pelagic sediments of the South Atlantic. Schneidermann showed that the dissolution zones become shallower as the latitude increases mainly due to the strong effect of cold bottom water (Fig. 6.1) (Schneidermann, 1973, 1977).

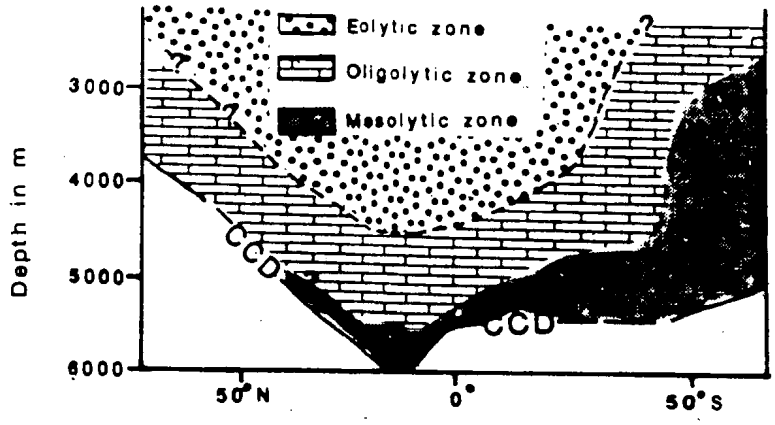
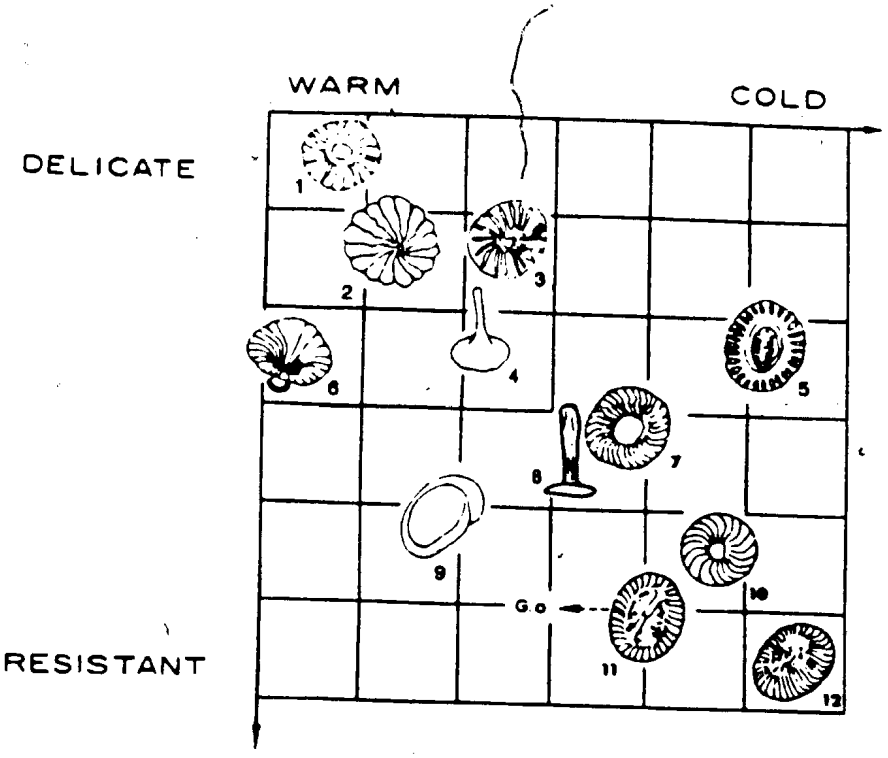


Fig. 6.1. Bathymetric subdivision of coccolith dissolution zones in the Atlantic Ocean (after Schneidermann, 1977).

The bathymetric location of Hole 647B belongs to Schneidermann's oligolytic zone which is characterized by the presence of well-preserved to partly dissolved placolith, highly dissolved specimens of S. pulchra and appendixes of Rhabdosphaera sp. (Schneidermann, 1977). In this study, the preservation state of placoliths is generally good throughout the core except for the presence of highly dissolved specimens of E. huxleyi. The preservation state of caneoliths is poor throughout the core; however, in a few intervals specimens of Pontosphaera sp. are well-preserved. The preservation state of cyrtoliths is poor throughout the core and only the appendixes of Rhabdosphaera sp. are preserved in most samples. Holococcoliths are not observed in this study. The preservation state of the observed coccoliths and the resultant assemblages indicate that Site 647 has been situated above the CCD, probably within the oligolytic zone through the studied interval.

Interrelationships between temperature-sensitive coccolith species and their susceptibility to dissolution are illustrated in Fig. 6.2. In general, warm water coccolith species are highly susceptible to dissolution because of their delicate and open-structured characteristics, whereas cold water species are more resistant because of their solid and dense characteristics (McIntyre and Bé, 1967). Therefore a floral assemblage affected by dissolution would reflect a colder environmental signal than the true one. Because many caneoliths, cyrtoliths and some placoliths of the coccolith assemblages in Hole 647B have shown evidence of partial dissolution, it is conceivable that these floral assemblages may be interpreted to indicate surface waters colder than the water temperature during deposition.

Fig. 6.2. Temperature-sensitive coccolith species and their susceptibility to dissolution. 1) Cyclolithella annula; 2) Cyclococcolithina fragilis; 3) Umbellosphaera tenuis; 4) Discosphaera tubifera; 5) E. huxleyi; 6) Umbellosphaera irregularis; 7) U. mirabilis; 8) R. mirabilis 9) H. kamptneri; 10) C. leptopora; 11) Gephyrocapsa sp.; 12) C. pelagicus (after Berger, 1973).


WARM
COLD
DELICATE
RESISTANT
1
2
3
4
5
6
7
8
9
10
11
12

6.1.2. PRODUCTIVITY

The production of planktonic foraminifera and coccolithophorids in surface waters has been considered one of the principal mechanisms controlling cyclic variations in carbonate content in Pleistocene deep-sea sediments (Arrhenius, 1952, 1963; Wiseman,1965). Biogenic carbonate productivity is very difficult to quantify (Gardner, 1982; Dean and Gardner, 1986). Arrhenius (1952) suggested that glacial stages are characterized by higher accumulation of calcium carbonate resulting from increased biological productivity due to intensified upwelling in the equatorial Pacific divergence. However, McIntyre et al. (1972) demonstrated that high latitude oceanic areas are different from low latitudes in the response of primary biological productivity to climatic fluctuations. They showed that in high latitudes glacial stages are characterized by minimum biological productivity, and in low latitudes by maximum productivity (Fig.6.3). Today Site 647 is located in the maximum productivity zone of the North Atlantic (McIntyre et al., 1972). Considering the latitudinal migration of the maximum productivity zone in response to climatic fluctuations, the overlying area of Site 647 may have experienced a large degree of surface productivity variations throughout the Pleistocene.

The relationship between the concentration of coccoliths in sediments and biogenic carbonate productivity in the overlying surface waters has been emphasized by McIntyre and his colleagues (McIntyre and McIntyre, 1971; McIntyre et. al., 1972; Ruddiman and McIntyre, 1976). According to McIntyre and McIntyre (1971), the highest concentration of coccoliths in the present North Atlantic is located beneath the northern margin of the subtropical gyre where the primary productivity is also high. However, downcore coccolith variations should be interpreted with caution because in some places, coccolith concentration is influenced by dissolution, bottom current winnowing, dilution

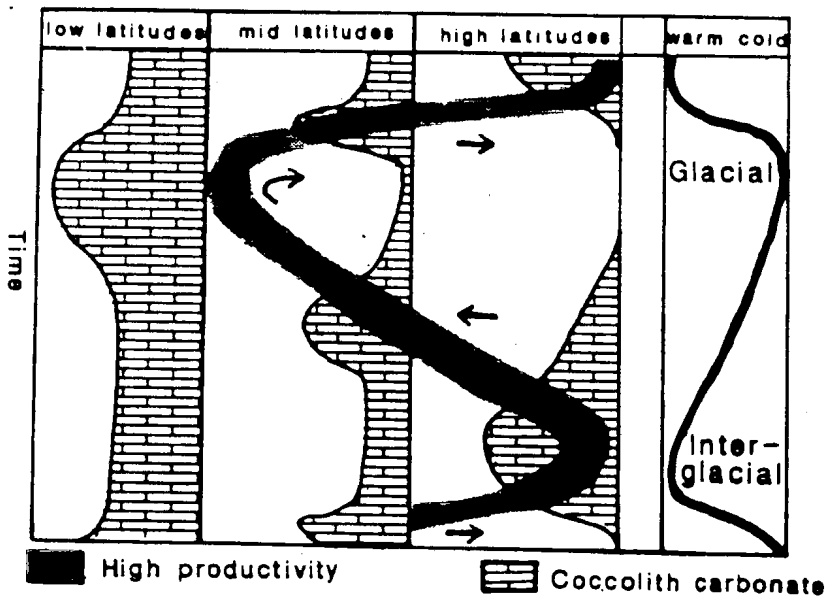


Fig. 6.3. Latitudinal migration of high productivity zone with respect to glacial-interglacial climatic fluctuations (after McIntyre et al., 1972).

by terrigenous sediments and the geological history (e.g., tectonic uplift) of the study area (Ramsay, 1972).

6.1.3. POSSIBLE CAUSES OF COCCOLITH ABUNDANCE CHANGES

The initial report (part A) of ODP Leg 105 (Srivastava, Arthur, Clement et al., 1987) indicated that coccoliths contributed significantly to the biogenic carbonate content of the cored sediments. The report also suggested that the lithologic variations of the cored sediments may be the result of dilution, dissolution of calcareous microfossils or productivity variations. Therefore, it will be necessary to understand the possible causes of coccolith abundance changes in order to interpret the floral data properly.

Aksu and Mudie (1985) suggested that variations in planktonic faunal and floral abundances are controlled by three main factors : dissolution cycles, changes in biological productivity, and changes in sedimentation rate. According to faunal data from Hole 647B, planktonic foraminiferal barren zone was not reported throughout the core and B/P ratio was much less than 1, which suggests that calcium carbonate dissolution was not too extensive to obliterate the productivity record in Site 647 (Aksu et al., in press). Poor correlation of the foraminiferal test fragmentation record with the oxygen isotopic and faunal records also indicated that dissolution is not a primary factor controlling downcore variations in faunal abundance in the area (Aksu et al., in press). Aksu et al. (in press) also suggested that change in sedimentation rate is not an important factor controlling downcore variations in faunal abundance of Hole 647. Therefore, downcore coccolith abundance changes in Hole 647B are likely to signal at least the first-order cycle of the primary biological productivity history of the southern Labrador Sea. However, it should be borne in mind that

dilution by terrigenous sediments, bottom current winnowing or dissolution of coccoliths as well as bioturbation and core deformation may have smoothed or exaggerated the productivity signals.

6.1.4. CALCAREOUS NANNOPLANKTON BIOGEOGRAPHY AND WATER-MASS DESIGNATIONS TO COCCOLITH ASSEMBLAGES

Based on both plankton (centrifugation and Millipore sampling) and surface sediment (trigger weight coring) samples from the Atlantic, McIntyre and Bé (1967) identified five climatic "coccolithophorid floral zones" : tropical, subtropical, transitional, subarctic and subantarctic (Fig. 6.4). The subarctic zone of the present Atlantic Ocean is characterized by the abundance of C. pelagicus and E. huxleyi and the minor presence of C. leptoporus, whereas the transitional zone is characterized by the dominance of E. huxleyi and C. leptoporus and the minor appearance of C. pelagicus (Table 6.1). Based on coccolith assemblages, McIntyre et al. (1972) defined three water-masses in the North Atlantic : subpolar water-mass dominated by E. huxleyi, G. caribbeanica and C. pelagicus ; transitional water-mass characterized by C. pelagicus and "cool subtropical species"; and. subtropical water-mass represented by S. pulchra, R. clavigera and G. ericsonii (Table 6.1). On the basis of surface water temperature ranges for modern coccolithophorids established by McIntyre and Bé (1967) in the Atlantic and by McIntyre et al. (1970) in the Pacific, McIntyre et al. (1972) assigned an optimal temperature range to each of these assemblages : subpolar species = 2-6°C; transitional species = 6-14°C; subtropical species = 12-28°C. Roche et al. (1975) employed the Imbrie and Kipp's (1971) paleoecological transfer functions and produced four coccolith assemblages entirely based on surface sediment samples of the North Atlantic : assemblage 1 dominated by C. leptoporus, variety C; assemblage 2 dominated by C. pelagicus;

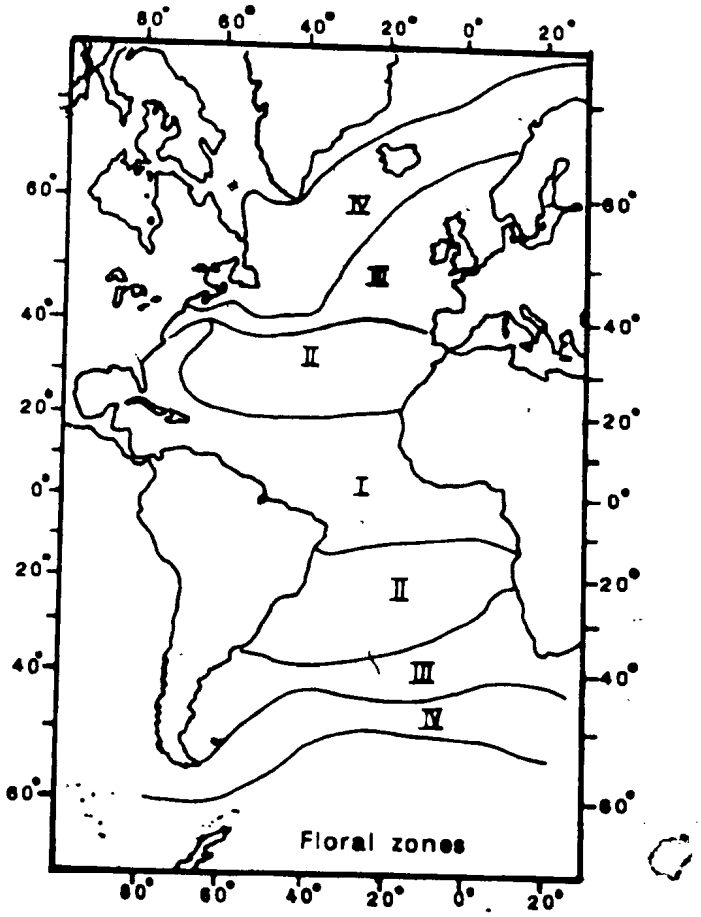


Fig. 6.4. Coccolithophorid floral zones of the Atlantic Ocean (I = tropical; II = subtropical; III = transitional; Iv = subarctic - subantarctic) (after McIntyre and Bé, 1967).

Table 6.1. Water mass designations to coccolith assemblages from the North Atlantic.

Water masses	Coccolith species		
	McIntyre and Bé, 1967	McIntyre et al., 1972	Ruddiman and McIntyre, 1976
Subpolar	C. pelagicus E. huxleyi C. leptoporus	E. huxleyi G. caribbeanica C. pelagicus	C. pelagicus
Transitional	E. huxleyi C. leptoporus G. ericsonii R. clavigera G. oceanica U. tenuis C. pelagicus	C. pelagicus "Cool subtropical species"	C. leptoporus variety C
Subtropical	U. tenuis R. clavigera D. tubifera C. annulus G. oceanica U. mirabilis H. kamptneri C. leptoporus C. fragilis E. huxleyi	S. pulchra R. clavigera G. ericsonii	C. sinuosa U. mirabilis U. tenuis R. clavigera S. pulchra U. irregularis

assemblage 3 dominated by U. mirabilis, R. clavigera, S. pulchra and Calciosolenia sinuosa; assemblage 4 dominated by G. oceanica. Because E. huxleyi has evolved from G. caribbeanica within the time interval under study, (the latest Pleistocene), these two species are ecologically unstable and vary in biogeographic range through the evolutionary interval (Roche et al., 1975). Therefore, E. huxleyi and G. caribbeanica have been eliminated from the Roche et al. analysis. By the comparison of the geographic distribution and the temperature-salinity characteristics of each assemblage with the surface currents and water masses in the North Atlantic, Roche et al. (1975) showed that assemblage 1 corresponds to the Gulf Stream-North Atlantic Drift and the Benguela Current; assemblage 2 characterizes the subarctic water-mass; assemblage 3 corresponds to the South Equatorial and Florida currents; and assemblage 4 corresponds to the Canary and Equatorial currents. Subsequently, assemblage 1, assemblage 2 and assemblage 3 have been designated as transitional, subpolar and subtropical "ecological water-masses", respectively by Ruddiman and McIntyre (1976) (Table 6.1).

6.2. PALEOENVIRONMENTAL INTERPRETATION OF COCCOLITHS

6.2.1. DOWNCORE VARIATIONS: COCCOLITH ABUNDANCES AND THEIR COMPARISON WITH THE OTHER PALEONTOLOGICAL, SEDIMENTOLOGICAL AND OXYGEN ISOTOPIC DATA

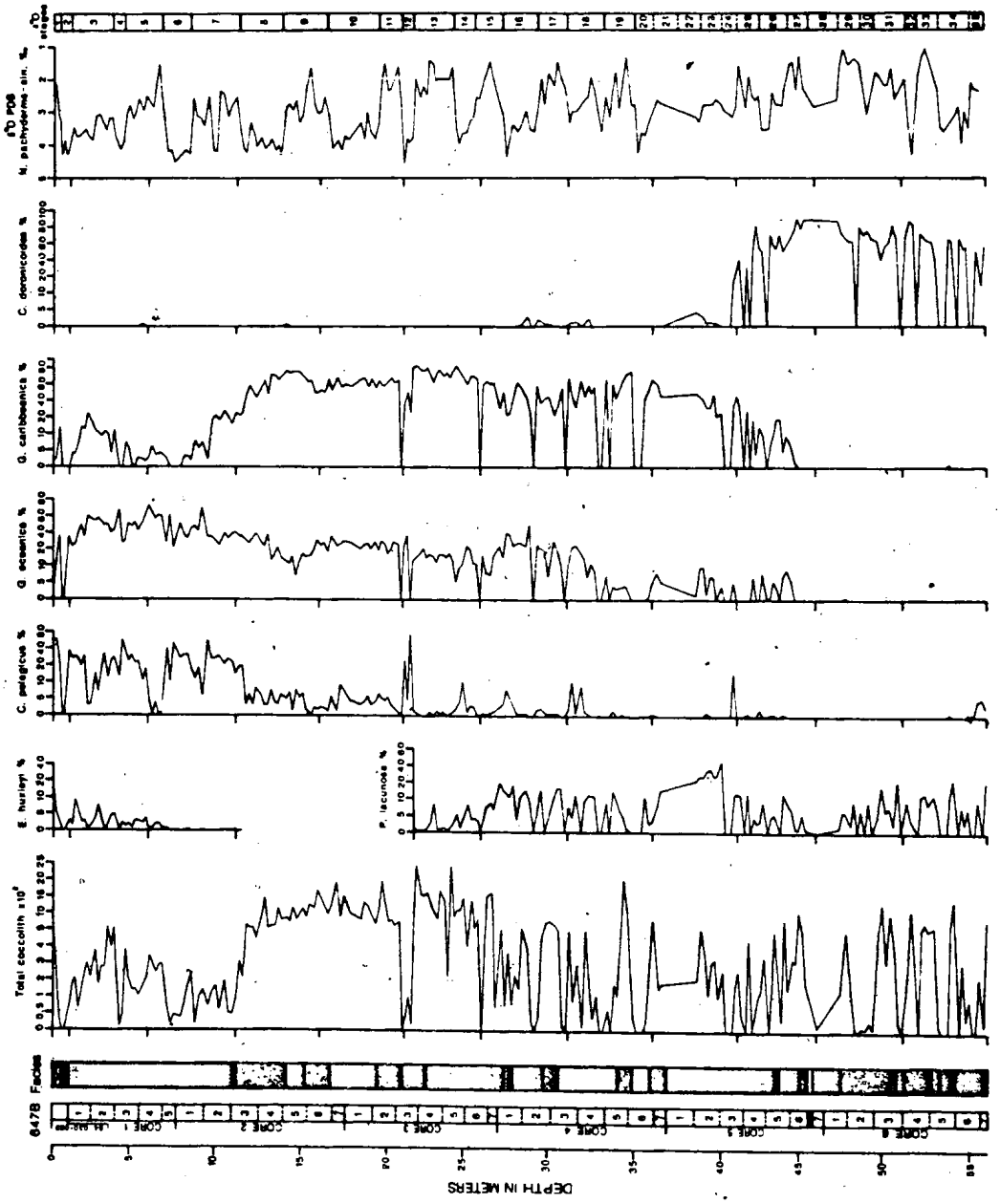
Abundances of total coccolith and some important species are plotted by depth (Fig. 6.5) and are compared with the sedimentological, planktonic foraminiferal, palynological and oxygen isotopic data from southern Labrador Sea cores (Srivastava, Arthur, Clement et al., 1987; de Vernal and Hillaire-Marcel, 1987a, 1987b; Aksu et al., in press). The total coccolith abundances greatly fluctuate throughout the interval studied. In general, glacial isotopic stages (particularly, 2, 4, 6, 20, 24 and 30) are characterized by low total

coccolith abundance although stages 8, 10 and 14 are characterized by relatively higher total coccolith abundance. It is noticeable that the early phases of glacial stages (e.g., 8, 12, 20, 22 and 24) are relatively high in abundance compared to the later phases. Most interglacial stages are characterized by higher total coccolith abundance. However, several interglacial stages of younger sediments e.g., oxygen isotope stages 1, 3, 5 and 7 are marked by much lower abundance than glacial stages 8, 10 and 14. A total of 27 samples (16 samples from glacial stages and 11 samples from interglacial stages) is barren of coccoliths. Among the barren samples from interglacial stages, 6 samples correspond to the glacial to interglacial transitions. However, the glacial to interglacial transition 6/5, where Hearn (1986) observed barren zones in Hudson 84-030-003, is characterized by increased number of coccoliths in this study.

E. huxleyi constitutes less than 10% of the flora through the interval from stage 1 to stage 7 except the uppermost part of stage 1 where the species forms up to about 25%. C. pelagicus is relatively abundant through the interval from stage 1 to stage 7, forming up to about 51%. Below stage 7, C. pelagicus constitutes much less than 20% except the highest peak (about 58%) in stage 12. E. huxleyi and C. pelagicus dominate the flora at the uppermost part of stage 1, constituting more than 70% of the total. Data from Northeast Atlantic (DSDP Hole 552A) and Norwegian Sea-Fram Strait cores also indicated that oxygen isotope stage is marked by high abundance peaks of E. huxleyi and C. pelagicus (Gard, 1986, 1988).

Considering the abundant occurrences of E. huxleyi (cold water variety) and C. pelagicus in the subpolar waters of the modern North Atlantic (McIntyre and Bé, 1967) and the modern North Pacific (McIntyre et al., 1970), the abrupt increase in the relative abundance of E. huxleyi and the high abundance of C. pelagicus at the upper most part of stage 1 may suggest an increasing role of the Labrador Current in the surface circulation patterns of the Labrador Sea during the later phase of the interglacial stage.

Fig. 6.5. Downcore abundances of total coccolith and selected species.


δ18O PDB
N. pachyderma - sin. %
C. donnicodes %
G. caribbeanica %
G. oceanica %
C. pelagicus %
E. huxleyi %
P. lacunosa %
Total coccolith x10⁸
Facies
8478
CORE 1
CORE 2
CORE 3
CORE 4
CORE 5
CORE 6
DEPTH IN METERS

It is also noticeable that the relative abundance of G. oceanica is considerably low at the uppermost part of stage 1. Due to an extremely low abundance of E. huxleyi except the topmost sample of stage 1, dominance reversal between E. huxleyi and Gephyrocapsa sp. complex is difficult to define accurately in this study. Considering highly corroded specimens of the observed E. huxleyi, the dominance reversal may have been partially masked by a selective dissolution of the more susceptible species, i.e. E. huxleyi as did so in Norwegian-Fram Strait cores (Gard, 1986). Except the upper part of stage 1, G. oceanica and C. pelagicus dominate the flora through the interval from stage 1 to stage 7, showing an internally reciprocal relationship between these two species. Oxygen isotope stage 5 is marked by a distinct mutual exclusion between these two species (a high abundance of G. oceanica and an extremely low abundance of C. pelagicus). Remarkably high abundance peaks of "small placoliths" comprising mainly Gephyrocapsa sp. were observed in stage 5 in Norwegian-Fram Strait cores (Gard, 1986, 1988).

It has been reported that G. oceanica characterizes relatively warm waters ranging from 13 to 26°C, optimally ranging from 17 to 23°C (McIntyre and Bé, 1967) and occurs abundantly in the modern Equatorial Atlantic (Geitzenauer et al., 1977). Honjo (1976) suggested that coccoliths produced in the Florida Strait could be transported to the Labrador Sea by the Gulf Stream within the same season. Therefore, it is conceivable that G. oceanica may have been transported by the Gulf Stream - North Atlantic Drift with other tropical species during that interval. However, considering that tropical and subtropical waters of the North Atlantic during the last 85,000 years were dominated by E. huxleyi (Theirstein et al., 1977) which recorded very low abundance in Hole 647B during most of that interval, the abundant occurrence of G. oceanica during that interval may be due to the increased local production of the species caused by the influence of warm North Atlantic Drift waters. In either case, the reciprocal relationship between C. pelagicus and G. oceanica probably reflect the interactions between

the cold Labrador Current and the warm North Atlantic Drift waters during that interval. Accordingly, the observed floral curves (the drastic decline in the abundance of C. pelagicus and the increasing abundance of G. oceanica) in oxygen isotope stage 5 may represent a dominant role of the Gulf Stream-North Atlantic Drift over the Labrador Current in the southern Labrador Sea during that interval.

G. oceanica and G. caribbeanica also show a reciprocal relationship in abundance. In general, G. oceanica dominates the flora through the interval from stage 3 to stage 7, forming up to 75% of the coccoliths. G. caribbeanica constitutes less than 25% of the coccoliths through the interval from stage 1 to stage 7, but the species dominates the flora through the interval from stage 8 to stage 24, forming up to 83% of the coccoliths. However, no particular relation to glacial or interglacial stages is observed in both species.

According to calcareous nannoplankton biogeographic studies based on plankton tow samples in the modern Pacific (McIntyre et al., 1970) and based on coccoliths in the sediments of the North Pacific and the North Atlantic (Geitzenauer et al., 1977), G. caribbeanica occurs in the tropical to subpolar region with a preference for cold waters. Because G. oceanica has been reported to have a preference for warm waters (McIntyre and Bé, 1967), it is conceivable that the reciprocal relationship between G. oceanica and G. caribbeanica reflects water-mass interactions, probably between cool and warm water-masses in the southern Labrador Sea. However, considering that G. oceanica has evolved from G. caribbeanica through the Pleistocene (Gartner, 1977), it is unlikely that the reciprocal relationship is entirely the result of such water-mass interactions.

Below stage 24, C. doronicoides dominates the flora, forming up to 91% of coccoliths, which results in a reciprocal relationship between G. caribbeanica and C. doronicoides in abundance. Sachs and Skinners (1973) suggested that G.

caribbeanica may have evolved from C. doronicoides during the early Pleistocene. The reciprocal relationship between the two species recorded in Hole 647B probably reflect the evolutionary change between them.

The transitional intervals (32/31, 20/19, 18/17 and 12/11) are marked by barren of coccoliths and abrupt decrease in planktonic foraminifera (Aksu et al, in press). The lithofacies of the transitional interval from glacial stage 12 to interglacial stage 11 is characterized by laminated detrital carbonate bearing clayey silts which have been interpreted as turbidites (Srivastava, Arthur, Clement et al., 1987). The lithofacies of the other transitional intervals (32/31, 20/19 and 18/17) are characterized by terrigenous silty clays which have been interpreted mainly as the product of ice-rafting (op. cit.). Therefore the four transitional intervals appear to be the result of dilution by glacial detritus input or terrigenous influx driven by turbidity currents during deglaciation. Suppressed biological productivity caused by the input of low-salinity and low-nutrient melt waters during deglaciation may have played a role in combination with the dilution by terrigenous sediments. Further studies particularly of siliceous and organic-walled microfossils are required to substantiate the possible contribution of low-nutrient melt water. In contrast, the other glacial to interglacial transitional intervals marked by barren of coccoliths are correlated with the relatively highest peaks of the planktonic foraminiferal abundance curve (Aksu et al, in press). Accordingly, those intervals are not likely to result from low-salinity melt water input or dilution by terrigenous sediments because the influx of terrigenous sediments by turbidity currents, glacial detritus input, or low-nutrient melt water input results in the same effect on planktonic foraminifera as does on coccoliths (McIntyre et al., 1972).

Dinocyst data from the site survey core 84-030-003 for Site 647 through oxygen isotopic stages 1 to 8 (de Vernal and Hillaire-Marcel, 1987a) provide supporting evidences for coccolith data. Dinocyst abundance throughout

isotopic stages 1 to 8 from the site survey core shows that glacial stages are characterized by low abundance of the flora except the higher abundance peaks during the ea ly phases of stages 6 and 8 (de Vernal and Hillaire-Marcel, 1987a). In general, the dinocyst abundance variations show a good correlation with coccolith abundance variations in this study. The overall decline in total abundances of the two phytoplanktonic microfossils during glacial intervals suggests that primary biological productivity was reduced during most glacial stages. Dinocyst assemblages from the site survey core show that warm-water species were persistently present throughout oxygen isotopic stages 1 to 8 except for a brief interruption during the late phase of stage 2 (de Vernal and Hillaire-Marcel, 1987a, 1987b). The presence of warm water species of both dinocysts and coccoliths throughout stages 1 to 8 with an interruption during the late phase of stage 2 perhaps indicates that the site was persistently influenced by warm North Atlantic surface water during the past ca. 0.3 Ma (Aksu et al., in press), with a brief interruption during the last maximum glaciation.

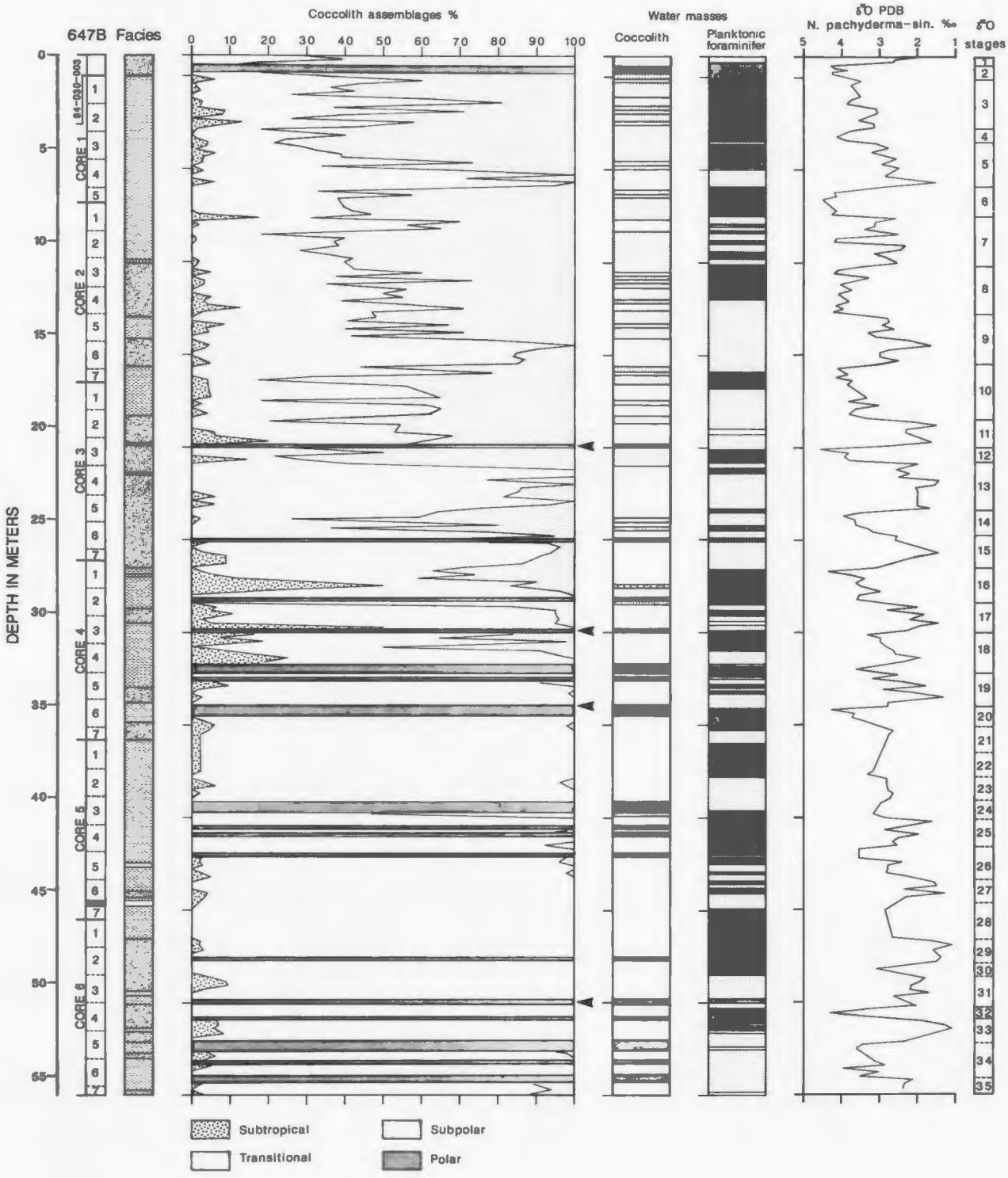
Pollen assemblages from Hole 647B also show that upper parts of interglacial stages 5 and 7 are marked by high pollen concentration, consisting dominantly of Picea (spruce tree pollen); and the early phases of glacial stages 4 and 6 are also marked by a large number of Picea pollen (Aksu et al., in press). The high pollen concentration during interglacial stages and the early phases of glacial stages appears to be compatible with coccolith data; however, the relatively low pollen concentration in southern Labrador Sea cores (84-030-003: de Vernal and Hillaire-Marcel, 1987a, 1987b; 647B: Aksu et al., in press) makes it difficult to attempt further detailed comparison.

6.2.2. HISTORY OF SURFACE WATER-MASSES

As pointed out by Aksu et al. (in press), the spatial distribution of the water-masses in the Labrador Sea throughout the Pleistocene cannot be determined with limited core coverage because the water-mass distribution of the Labrador Sea is controlled by complex interactions between the North Atlantic Drift, the Labrador Current and the West Greenland Current. Therefore, in this study, only the temporal distribution of water-masses in the overlying area of Site 647 is reconstructed primarily based on the coccolith assemblages from Hole 647B. The reconstructed ecological water-masses are related to polar front migration and changing circulation patterns of the surface currents, particularly the interactions between the warm North Atlantic Drift and the cold Labrador Current by the comparison with regional paleoceanographic trends in the Labrador Sea. Ruddiman and McIntyre's (1976) ecological water-mass designations to coccolith assemblages are employed in this study. Ruddiman and McIntyre (1976) designated three water-masses as follows : subpolar water-and drastically increases toward the lower part of the mass characterized by C. pelagicus; transitional water-mass characterized by C. leptoporus; subtropical water-mass characterized by U. mirabilis, R. claviger and S. pulchra. Because calcareous nannoplanktons are not present in polar waters, polar water-mass is defined by barren of coccoliths which is correlative with a maximum development of polar fauna (Neogloboquadrina pachyderma sinistral) (Ruddiman and McIntyre, 1976).

The temporal distribution of the floral assemblages and the reconstructed ecological water-masses are shown in Fig. 6.6. All the coccolith barren zones including the transitional intervals (32/31, 20/19, 18/17 and 12/11)are attributed to the presence of polar water-masses although low-nutrient input or dilution by terrigenous sediments appears to be responsible for the barren zones

Fig. 6.6. History of surface water-masses in Site 647. Assemblage % indicates "the amount of each floral assemblage component species" calculated from the total sum of the flora used in water-mass designation. The barren intervals which appear to be influenced by dilution or low-nutrient melt water input are indicated by wedge mark (⊢). Planktonic foraminiferal water-masses are from Aksu et al. (in press).


647B Facies
Coccolith assemblages %
0 10 20 30 40 50 60 70 80 90 100
Water masses
Coccolith
Planktonic foraminifer
δ18O PDB
N. pachyderma-sin. ‰
5 4 3 2 1
δ18O stages
DEPTH IN METERS
CORE 1
CORE 2
CORE 3
CORE 4
CORE 5
CORE 6
Subtropical
Transitional
Subpolar
Polar

of the transitional intervals. Subpolar assemblage is relatively abundant in stages 1 to 7, particularly in the upper part of stage 1. Transitional assemblage is persistently present throughout the entire interval although the assemblage tends to be more abundantly distributed in the lower part of the section, particularly in stages 23, 29, 31, 33 and 35. Subtropical assemblage is also persistently present through the almost entire interval but are extremely limited in relative abundance. In general, the upper part of Hole 647B - stages 1 to 12/13, 0 to ca. 0.472 Ma (Shackleton and Opdyke, 1976) is dominated by subpolar and transitional water-masses with an incursion of polar water-masses during the later phase of glacial stage 2, whereas the other part - stages 12/13 to 35/36, ca. 0.472 Ma to ca. 1.076 Ma (Ruddiman, Raymo and McIntyre, 1986) is persistently dominated by transitional water-masses with sporadic incursions of polar water-masses during isotopic stages 15, 16, 18, 19, 20, 24, 25, 26, 29, 31, 32, 33 and 34. It is noticeable that the early phases of several glacial stages, particularly stages 2, 4, 6, 8, 10, 12, 14, 20, 24 are characterized by transitional or subpolar water-masses.

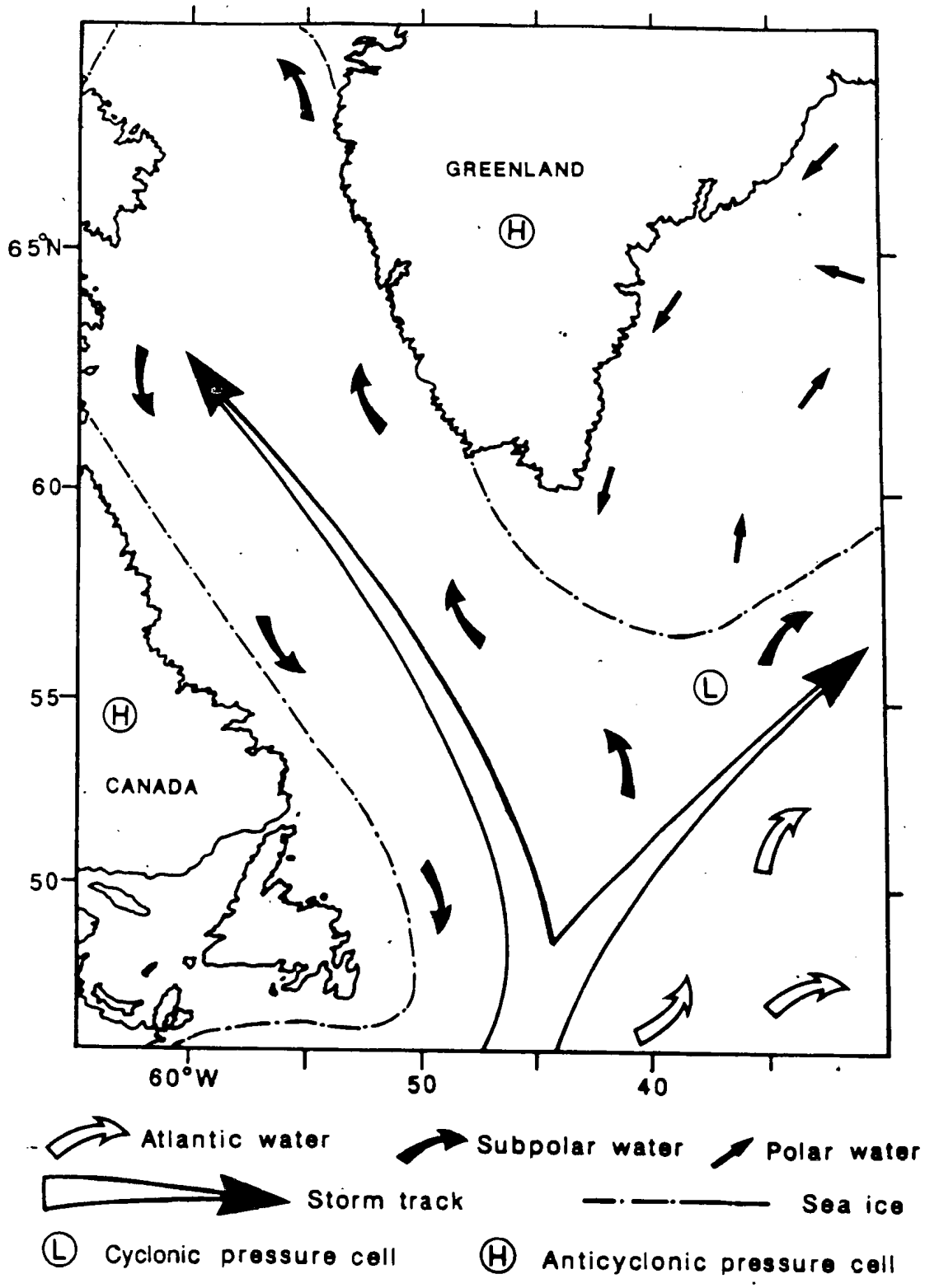
The presence of coccolith-barren zones during the late phase of glacial stage 2 may indicate increased influence of cold Labrador Current water comparable to the present-day inner Labrador Current water and southward migration of polar front during a severe cold interval of the glacial stage. The cold interval has been reported also from central North Atlantic cores (Ruddiman and McIntyre, 1981b), from the eastern Grand Banks slope and Flemish Pass areas (Alam et al., 1983), and from Norwegian-Fram strait cores (Gard, 1986).

The presence of transitional or subpolar water-masses during the early phases of several glacial stages is compatible with the faunal and floral data from Labrador Sea and Baffin Bay cores (Mudie and Aksu, 1984; Fillon and Aksu, 1985; Aksu and Mudie, 1985) which suggested northward advection of warm

North Atlantic water via channelized storm tracks during the initial intervals of major ice growth phases. The paleoceanographic conditions in the Labrador Sea during the early phases of several glacial stages are delineated by the paleoceanographic map reconstructed by Aksu and Mudie (1985) primarily based on the faunal and floral data from Labrador Sea and Baffin Bay cores (Fig. 6.7).

In general, ecological water-masses deduced from the coccolith assemblages from Hole 647B reflect warmer paleoclimatic trends than those from the planktonic foraminiferal assemblages from the same samples (Aksu et al., in press). For instance, the planktonic foraminiferal data indicate that Hole 647B is dominated by subpolar and polar water-masses, whereas the floral data indicate that Hole 647B is dominated by transitional and subpolar water-masses (Fig. 6.6). The colder response of the planktonic foraminiferal assemblages may be attributed to the fact that planktonic foraminifera tend to live in a greater depth in the vertical water column of the ocean compared to coccolithophorids, resulting in a colder temperature signal for the foraminifera than for the coccolithophorids (Ruddiman and McIntyre, 1976). However, it should be noted that ecological water-masses defined by planktonic foraminiferal assemblages are different from those defined by coccolith assemblages. For instance, the former were designated by using the percentage limits of composition species which often result in the discrepancy between ecological water-masses and physical oceanographic water-masses (Aksu et al., in press), whereas the latter were designated without using any percentage limit. Furthermore, the lack of floral counterpart for the polar fauna, N. pachyderma (sinistral) may have caused the partial disagreement between the two results, particularly in the temporal distribution of polar water-masses.

Fig. 6.7. Paleoceanographic map of the high-latitude northwest Atlantic during early glacial periods, showing atmospheric pressure system, storm tracks, surface water circulation patterns and sea-ice cover (redrawn from Aksu and Mudie, 1985).


GREENLAND
H
65°N
60
55
H
CANADA
L
50
60°W
50
40
Atlantic water
Subpolar water
Polar water
Storm track
Sea ice
L Cyclonic pressure cell
H Anticyclonic pressure cell

6.2.3. MID-PLEISTOCENE TRANSITION IN MILANKOVITCH CYCLES AND ITS POSSIBLE PALEOCEANOGRAPHIC SIGNAL IN COCCOLITH RECORD

As discussed in CHAPTER 1 (section 1.2.2), several paleoenvironmental markers, particularly oxygen isotope record of marine microfossils from world oceans indicated that dominant climatic cycles shifted from 41,000 years periodicity to 100,000 years periodicity near mid-Pleistocene (approximately 0.6-0.9 Ma). Gartner and his colleagues (Gartner et al., 1983, 1987; Gartner, 1988) reported that the mid-Pleistocene interval (0.93-1.25 Ma) of several low-latitude oceanic cores is marked by an "acme horizon" of small Gephyrocapsa (<3μm) and its upper boundary is characterized by an abrupt increase in large Gephyrocapsa (>3μm). Gartner et al. (1983) postulated that the dominant occurrence of small Gephyrocapsa during the mid-Pleistocene might reflect an abnormally high productivity interval caused by vigorous equatorial upwelling driven by ice-free Arctic Ocean. According to Gartner (1988), paleoceanography of the mid-Pleistocene (0.93-1.25 Ma) was considerably different from that of the late Pleistocene, possibly in response to the mid-Pleistocene shift in dominant climatic periodicities, i.e. from 41.000 years to 100.000 years.

Among the various species of the genus Gephyrocapsa identified in this study, G. aperta (<2.5 μm) belongs to small Gephyrocapsa of Gartner (1988). However, this species is observed sparsely through the studied interval with relatively low abundances (never exceeding 30% of the total flora). Moreover, G. aperta is almost absent near the top of Jaramillo magnetic event. Consequently, the mid-Pleistocene small Gephyrocapsa dominance interval of Gartner (1988) is not found to occur in the studied interval of Hole 647B. Instead, an overwhelming dominance of C. doronicoides (mostly 4-5.5 μm) is observed just prior to the top of Jaramillo magnetic event, i.e. below oxygen isotope stage 25 (Fig. 6.5). The relationship between the small Gephyrocapsa dominance interval

in low latitude oceanic cores (Gartner, 1988) and the C. doronicoides dominance interval in Hole 647B deserves to be carefully investigated because these two dominance "episodes" occur just prior to the mid-Pleistocene (0.9-0.6 Ma) shift in dominant climatic cycles, from 41,000 years to 100,000 years periodicities (Ruddiman, Backman et al., 1987). However, paleoceanographic information which can be inferred from C. doronicoides is limited primarily because the ecology of the species is incomplete today. Nonetheless, the possibility that C. doronicoides dominance interval will be a useful tool for revealing high-latitude oceanic condition during the mid-Pleistocene climatic transition cannot be eliminated. Further detailed study of other high latitude oceanic cores is required to determine whether the mid-Pleistocene C. doronicoides dominance interval is a local phenomenon or global one.

CHAPTER 7

MULTIVARIATE PALEOECOLOGICAL ANALYSIS

To interpret the coccolith census data more objectively, cluster and factor analyses were performed on the data matrix consisting of 17 variables and 242 cases.

7.1. CLUSTER ANALYSIS

Cluster analysis is one of the most objective methods to recognize relationships between variables or between samples in a large data matrix. The same data matrix can be analyzed by both R-mode where variables are compared and Q-mode where samples are compared. Q-mode analysis has been more commonly used in paleoecology than R-mode analysis simply because the result of Q-mode analysis can be easily correlated with sedimentary facies; however, R-mode analysis also is useful, particularly in observing possible interactions between species i.e., co-occurrence and mutual exclusion among species (Dodd and Stanton, 1981). In this study both R-mode and Q-mode cluster analyses were performed on the same data matrix to recognize species associations or interactions and to classify the samples into discrete groups, respectively. The principle of cluster analysis and its application to sedimentologic and paleoecologic studies are illustrated in numerous publications e.g., Purdy (1963), Kaesler (1966), Parks (1966), Harbaugh and Merriam (1968), Gevirtz et al., (1971), Sneath and Sokal (1973), Park (1974) and Feldhausen and Ali (1974, 1976).

7.1.1. R-MODE

To measure the similarity between variables, cosine similarity coefficient, which has been proven to be successful in sedimentary environmental studies (Imbrie and Purdy, 1962), was used. Although scaling of data (converting the raw data into a form ranging from 0 to 1) has been preferred for R-mode analysis (Park, 1974), the raw data matrix (percentage measures) was not scaled in this study primarily because angular measure of similarity such as cosine similarity coefficient tends to be seriously affected by scaling operation (Sneath and Sokal, 1973). The raw data matrix, consisting of 17 variables and 242 cases, produced the cosine similarity coefficient matrix between 17 variables by using the SPSS-X subprogram "proximities" (SPSS-X User's Guide, 1988). The raw data matrix and the cosine similarity coefficient matrix between 17 variables are listed in Appendix I and Appendix II, respectively. Subsequently, the similarity matrix was analyzed by Average Linkage Between Groups method (pair by pair comparison between variables) which is one of the most commonly used clustering methods (Romesburg, 1984) . R-mode dendrogram showing the interrelationships between the variables is illustrated in Fig. 7.1. The highest distance (25) in the dendrogram indicates the strongest dissimilarity between the groups, whereas the lowest distance ($\sim$0) indicates the strongest similarity. The resulting cluster groups may reflect the environmental interrelationships between the variables (Purdy, 1963). That is, the species grouped into the same cluster at lower distances may indicate that they have reacted similarly to environmental changes. The first four cluster groups which clustered at relatively lower distances are described as follows:

Cluster group 1: Cluster group 1 consists of C. pelagicus, G. oceanica and E. huxleyi. The first two species were clustered with the highest similarity among the 17 variables. Apparently, R-mode cluster analysis seems to have ignored the

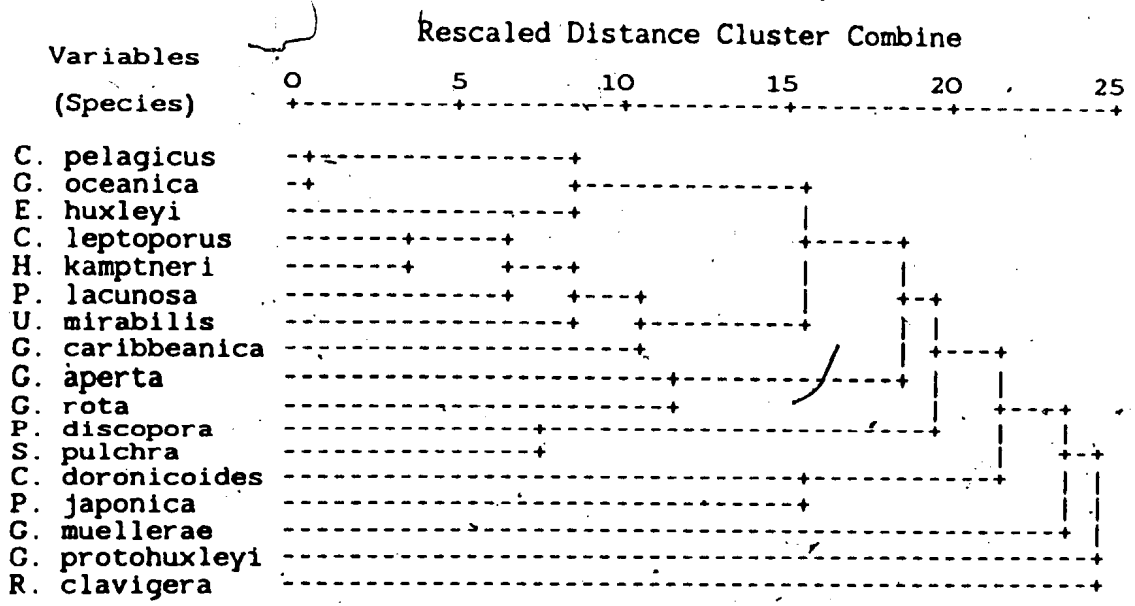


Fig. 7.1. R-mode dendrogram showing the interrelationships between the floral species through the interval studied.

second-order cycle, the internally reciprocal relationship between C. pelagicus and G. oceanica which has been discussed in the previous chapter, recognizing only the first-order cycle of each species and resulting in the highest similarity between the two species. Because of the inability to recognize the second-order cycle, R-mode cluster analysis seems to have clustered both the cold water species, C. pelagicus and the warm water species, G. oceanica with such a high similarity. Therefore, caution is required for the accurate interpretation of the resultant cluster groups. However, despite such limitation of cluster analysis, the assemblage of this cluster group is interpreted to reflect possible interactions between the cold Labrador Current and the warm North Atlantic Drift or coexistence of the two contrasting currents at the overlying area of Site 647 during the interval studied.

Cluster group 2: Cluster group 2 consists of C. leptoporus, H. kamptneri, P. lacunosa, U. mirabilis and G. caribbeanica. The assemblage of this cluster group characterizes a warm water influence although G. caribbeanica has been reported as an eurythermal species with a preference for cool water (McIntyre et al., 1970; Geitzenauer et al., 1977). Despite the predominant occurrence of G. caribbeanica and much smaller occurrence of U. mirabilis through the interval studied, the two species were clustered together. This is probably because the similarity measuring method (cosine θ) employed in this study essentially recognizes the similar shapes or patterns regardless of the size displacement between the data profiles (Romesburg, 1984).

Cluster group 3: Cluster group 3 consists of G. aperta and G. rota. The two species are relatively small ($< 2\mu m$) in size. The specimens assigned to the two species in this study are comparable to small Gephyrocapsa sp. of Gartner (1988) in size. Gartner et al. (1983, 1987) referred small Gephyrocapsa sp. to a productivity signal. Therefore, the component species may have been clustered due to similar productivity responses. However, the scattered and limited

occurrences of the two species throughout the interval studied make it difficult to apply the two species to interpreting the productivity history.

Cluster group 4: Cluster group 4 consists of P. discopora and S. pulchra. It is interesting to note that these two species produce caneoliths (basket-shaped coccoliths) which are susceptible to dissolution. The component species may have been clustered together due to similar responses to the floral dissolution. However, considering the occurrence of relatively well preserved specimens of these two species (CHAPTER 6), it is also conceivable that ecological or depositional factors have contributed to the formation of this cluster group. Gartner et al. (1987) inferred a hemipelagic signal based on the enhanced preservation of S. pulchra in Caribbean cores. Because S. pulchra has been considered as a warm water indicator (Ruddiman and McIntyre, 1976), it is inferred that the component species may reflect a warm water influence.

The other cluster groups which were clustered at relatively lower levels of similarities seem less meaningful. Nevertheless, it is interesting to note that G. protohuxleyi and R. clavigera formed independent entities, reflecting strong dissimilarities with the other species. The two independent entities are probably due to the extremely isolated occurrences of both species throughout the interval studied.

7.1.2. Q-MODE

To recognize stratigraphic and environmental signals by grouping the samples according to the similarity of the floral assemblages, Q-mode cluster analysis was performed on the same data matrix. Several authors (Parks, 1966; Park, 1974; Feldhausen and Ali, 1974) have suggested that the highly correlated

variables of R-mode cluster analysis are to be eliminated to reduce the redundancy which often brings about the biased results of Q-mode cluster analysis. However, this was not the case. All the species composition was retained in this study to protect any subtle environmental parameter from being lost. Distance coefficients between samples, which have been preferred for environmental studies (Park, 1974), were calculated in a Squared Euclidean distance. Ward's method was used to group the samples based on the distance coefficients.

The interrelationships between the resulting main cluster groups A, B, C and D are illustrated in Q-mode dendrogram (Fig. 7.2). The cluster groups A, B, and C are subdivided into the cluster subgroups A1, A2, B1, B2, C1, and C2. Species composition of the cluster subgroups A1 to C2 is plotted in Fig.7.3. The percentages of the species are average composition for all samples of each cluster subgroup. The relative abundance of the main component species of each cluster subgroup can be summarized as follows:

Cluster subgroup A1 : Cluster A1 is dominated by G. oceanica (56.92%). C. leptoporus, G. caribbeanica and C. pelagicus constitute 13.75%, 10.17% and 8.34% of the total coccolith abundance of cluster A1, respectively. The other nine species are the minor constituents of cluster A1, each species rarely exceeding 2% except G. aperta (3.98%) and H. kamptneri (2.60%).

Cluster subgroup A2 : Cluster A2 is dominated by G. oceanica (34.29%) and C. pelagicus (31.71%). C. leptoporus and G. caribbeanica are relatively abundant, constituting 16.61% and 10.23%, respectively. The other nine species are the minor constituents, each species constituting much less than 1% except H. kamptneri (2.36%), E. huxleyi (2.25%) and G. aperta (2.11%).

Cluster subgroup B1 : Cluster B1 is dominated by G. caribbeanica (40.06%).

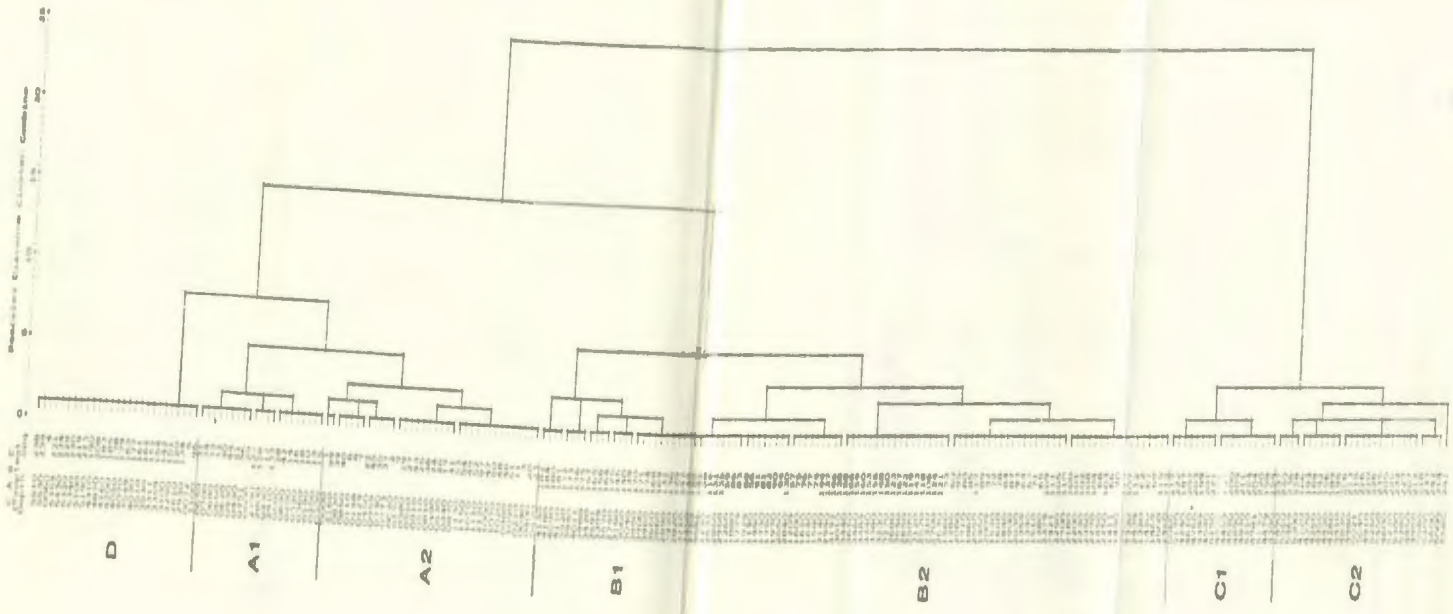


Fig. 7.2. Q-mode dendrogram showing the interrelationships between the studied samples.

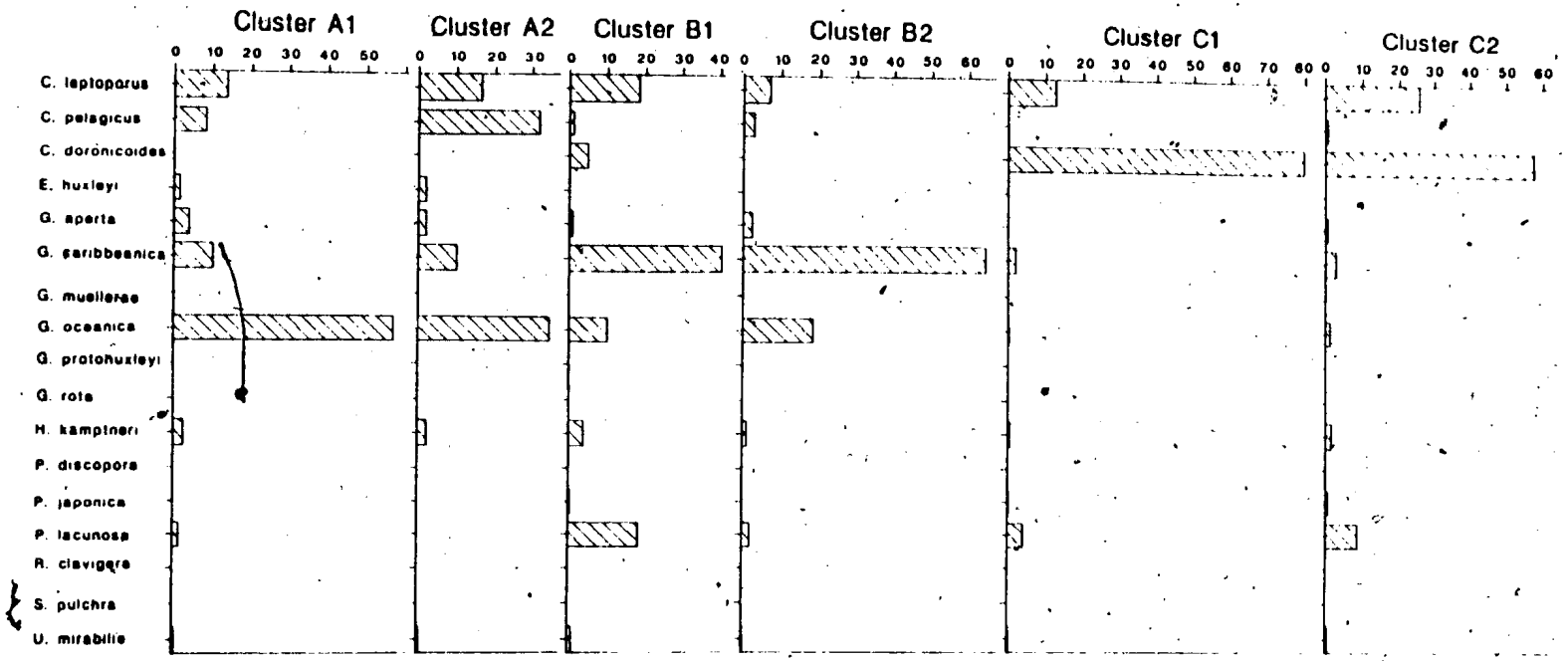


Fig. 7.3. Average species composition of the Q-mode cluster groups.

The next abundant species are C. leptoporus (18.33%), P. lacunosa (18.22%) and G. oceanica (9.98%). The other ten species are the minor constituents, each species rarely exceeding 1% except C. doronicoides (4.90%) and H. kamptneri (3.86%).

Cluster subgroup B2 : Cluster B2 consists predominantly of G. caribbeanica (64.32%). The next abundant species are G. oceanica (18.71%) and C. leptoporus (7.16%). The other thirteen species are the minor constituents, each species rarely exceeding 1% except C. pelagicus (3%), G. aperta (2.39%) and P. lacunosa (2.16%).

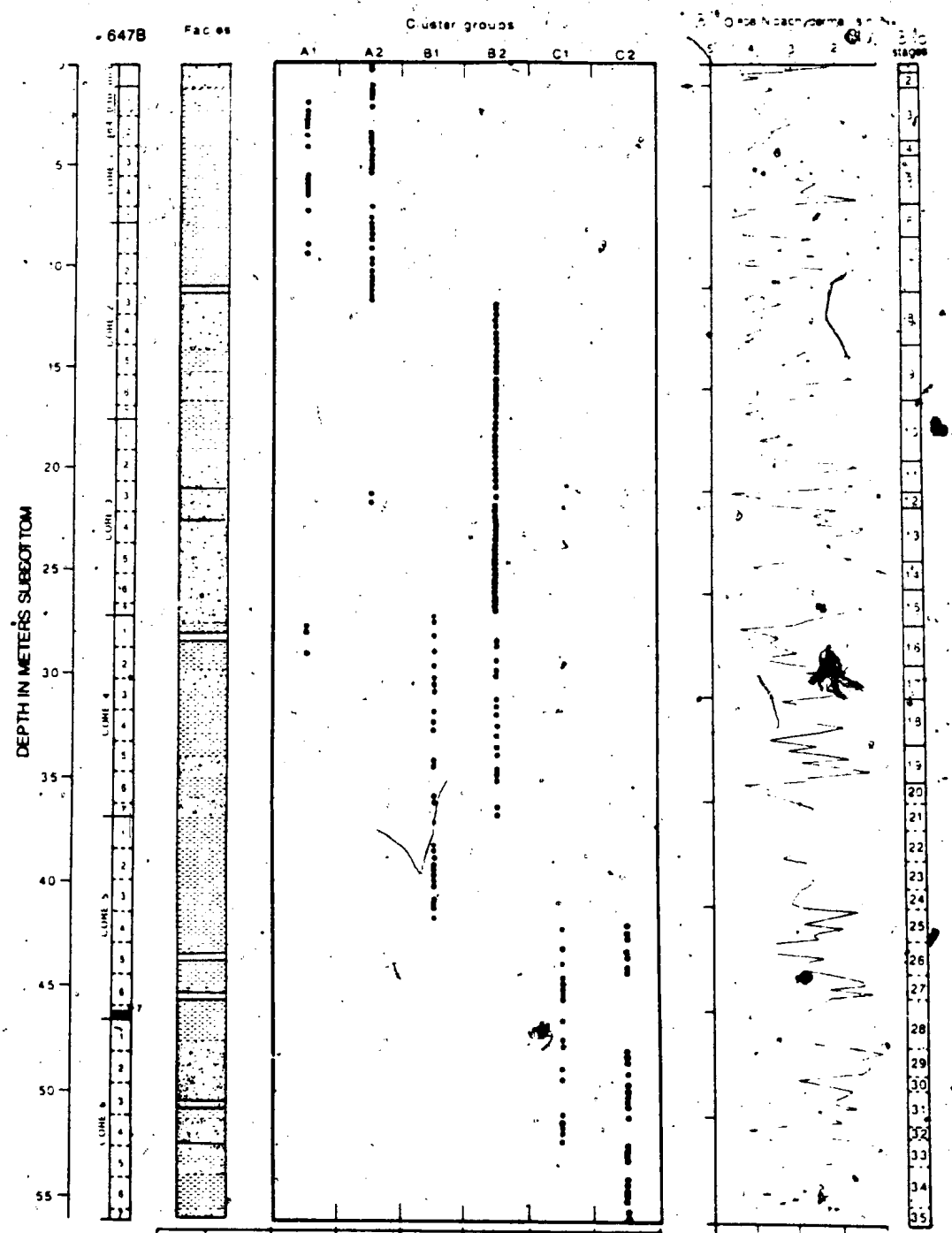
Cluster subgroup C1 : Cluster C1 is overwhelmingly dominated by C. doronicoides (79.39%). The next abundant species are C. leptoporus (12.73%) and P. lacunosa (4.15%). G. caribbeanica and G. oceanica are considerably low in abundance compared to cluster groups A and B, constituting only 2.12% and 0.36%, respectively. The other six species are much less than 1% in abundance.

Cluster subgroup C2 : Cluster C2 is also dominated by C. doronicoides (57.42%).The next abundant species are C. leptoporus (25.43%) and P. lacunosa (8.50%). The abundance of G. caribbeanica and G. oceanica is low, constituting only 2.98% and 1.40%, respectively. The other ten species are the minor constituents, each species comprising less than 1% except H. kamptneri (1.71%).

Cluster group D : Cluster D consists of all samples barren of coccoliths.

In an attempt to recognize significant stratigraphic and environmental signals manifested in the floral assemblages, the distribution of the cluster groups by depth is correlated with the lithofacies and planktonic foraminiferal oxygen isotope stratigraphy (Fig.7.4).

Fig. 7.4. Stratigraphic distribution of the Q-mode cluster groups.



Number of samples							
	Facies	5	12	11	39	7	12
	Interfacies	16	24	17	44	11	17
	Total	21	36	28	83	18	29

Most samples of the cluster group A are distributed above the oxygen isotopic stage 7 where sediments are dominated by facies A and the total coccolith abundances are relatively low (Fig. 6.5). In combination with the lithofacies and the total floral abundance variation, the assemblages of the cluster subgroups A1 and A2 which contain the high proportion of C. pelagicus suggest that the area near Site 647 was relatively cool during the stratigraphic interval (above oxygen isotopic stage 7) compared to the older interval. The stratigraphic level marked by the distribution boundary between the cluster group A and the group B approximately coincides with the FAD of E. huxleyi detected in this study (Fig. 5.1). Sediments in this level are characterized by laminated detrital carbonate beds, interpreted as turbidites.

All samples of the cluster group B are distributed between the oxygen isotopic stage 8 and the stage 25 where biogenic carbonate components are relatively dominant in the sediments; the total coccolith abundances are relatively high and fluctuate greatly (Fig. 6.5). The boundary between the distribution of the cluster subgroup B1 and that of the subgroup B2 can be correlated with the Brunhes/Matuyama magnetic chron boundary (Fig. 5.1), ca. 0.73 Ma (Srivastava, Arthur, Clement et al., 1987) although the distribution boundary between the two subgroups is not as clearly defined as the boundary between the cluster groups A and B or between the cluster groups B and C.

All samples of the cluster group C are distributed below the oxygen isotopic stage 25. The boundary between the cluster group B and the group C is clearly defined in the oxygen isotopic stage 25. The cluster boundary is placed slightly above the top of Jaramillo magnetic event (Fig. 5.1), ca. 0.91 Ma (Srivastava, Arthur, Clement et al., 1987). The boundary between the cluster group B and C is characterized by the shift from C. doronicoides to G. caribbeanica. The boundary marked by the shift in dominant species seems to be correlatable with that marked by the shift from a dominant small

Gephyrocapsa sp. to large G. oceanica at ca. 0.93 Ma in the northeastern Gulf of Mexico (Gartner et al., 1983). The dominance interval of small Gephyrocapsa sp. has been attributed to an abnormally higher productivity interval caused by vigorous equatorial upwelling during that period, ca 1.25 to 9.3 Ma (Gartner et al., 1983). Although it is uncertain whether the dominance interval of C. doronicoides in Hole 647B has a direct relationship with the dominance interval of small Gephyrocapsa sp. in the northeastern Gulf of Mexico, it is noticeable that both intervals approximately coincide with the middle Pleistocene time interval (ca. 0.9 to 0.6 Ma) marked by a major shift in climatic response of the North Atlantic i.e., from the periodicity of 41,000 years to that of 100,000 years (Ruddiman, Backman et al., 1987). Gartner et al. (1983, 1987) suggested that shifts in species composition and their relative abundances reflect environmental changes. Considering the phylogenetic relationship between C. doronicoides and G. caribbeanica (Sachs and Skinner, 1973), the cluster boundary marked by the shift in dominant species appears to be the result of an evolutionary change from C. doronicoides to G. caribbeanica, perhaps resulting from the fundamental causes of the shift from short to long climatic periodicities (Ruddiman, Backman et al., 1987).

7.2. FACTOR ANALYSIS

Factor analysis is an effective tool to recognize simplifying relationships out of complex data matrix. In R-mode factor analysis the same variable may be assigned to different factors, which is contrasted with R-mode cluster analysis where the same variable is restricted to only one cluster group. Therefore, performing both R-mode cluster analysis and R-mode factor analysis on the same data matrix will not be redundant but be complementary. It has been reported that Q-mode cluster analysis and Q-mode factor analysis give similar results

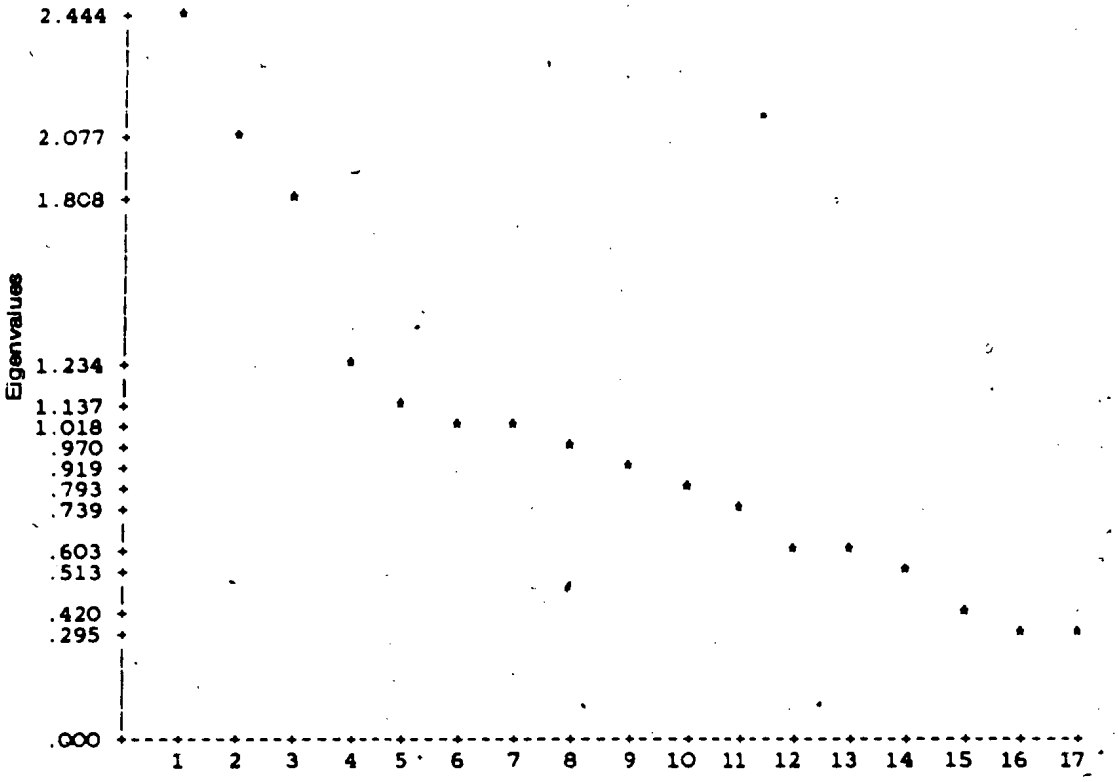
(Parks, 1966). Because Q-mode cluster analysis has provided satisfiable results, Q-mode factor analysis is not performed in this study. Only the result of R-mode factor analysis is discussed in the following. The theory of factor analysis is well described in Rummel (1970), Comrey (1973) and Cattell (1978); its application to geological problems has been proven to be successful e.g., Imbrie and Purdy (1962), Klovan (1966), Harbaugh and Merriam (1968), Imbrie and Kipp (1971) and Davis (1973).

Although morphologically similar or phylogenetically related species have been used as a combined variable (e.g., Gartner et al., 1987), every coccolith species identified in this study was used as an individual variable without any combination of phylogenetically related species primarily because some of the phylogenetically related species are known to have different environmental signals e.g., G. oceanica and G. caribbeanica. Therefore, both phylogenetic and environmental influences on the formation of factors are expected.

In order to extract underlying factors out of the correlation matrix between the variables, principal component analysis was used. Seven factors were chosen by using the eigenvalue-one criterion which set the cutoff point at the minimum eigenvalue of 1.0 (Rummel, 1970). Because the extracted factors in an unrotated factor matrix are often difficult to interpret (Comrey, 1973), the factor matrix was rotated by using orthogonal varimax rotation. The eigenvalues for the seven factors (the sum of the squared factor loadings in each factor) and the percentage of variance accounted for by each factor is illustrated in Fig. 7.5. The rotated factor matrix with the communality values for each variable (the proportion of each variable's total variation) is shown in Table 7.1. The graphical representation of the extracted factors is also illustrated in Fig. 7.6.

G. muellerae, H. kamptneri, P. japonica and U. mirabilis are considerably low in communality values (less than 0.5), meaning that more than 50 percent of

Fig. 7.5. Eigenvalues and the percentage of variance for the extracted factors.



Factor	Eigenvalue	Percentage of variance	Cumulative percentage
1	2.44368	14.4	14.4
2	2.07683	12.2	26.6
3	1.80845	10.6	37.2
4	1.23364	17.3	44.5
5	1.13739	6.7	51.2
6	1.06179	6.2	57.4
7	1.01754	6.0	63.4

Table 7.1. Rotated factor matrix with communality value for each variable.

VARIABLES	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	COMMUNALITY
1	0.15589	0.55125	0.50933	-0.01894	0.05947	-0.03584	-0.00800	0.59283
2	0.83602	0.08061	-0.04966	-0.04508	-0.04622	-0.02714	-0.05560	0.71589
3	-0.39133	0.78751	0.01552	0.04414	-0.09504	0.01266	-0.04702	0.78691
4	0.69174	0.13954	0.04338	0.06409	-0.06162	0.11313	-0.13604	0.53907
5	0.15506	-0.11883	-0.06063	0.12901	0.78695	-0.21987	0.14364	0.74675
6	-0.26579	-0.80883	0.02611	-0.01481	0.08185	0.06490	-0.00616	0.73670
7	0.02197	-0.12763	0.09838	0.05989	0.09282	0.61721	-0.03728	0.42099
8	0.68170	-0.30620	-0.03622	-0.01135	0.17285	-0.09237	0.27255	0.67261
9	-0.06039	-0.01588	-0.00441	-0.01029	0.00629	0.07833	0.92773	0.87089
10	-0.14811	-0.01599	0.06381	-0.06498	0.80962	0.24234	-0.11390	0.75767
11	0.16815	-0.08313	0.56337	0.25726	0.06144	-0.04377	0.21142	0.46914
12	-0.15250	0.06961	0.05714	0.82265	-0.04491	0.11733	-0.07230	0.72912
13	-0.16413	0.10188	0.57828	-0.16131	-0.00554	0.00158	-0.03957	0.39935
14	-0.39339	0.05788	0.64922	0.04472	-0.12681	-0.01138	-0.03451	0.59899
15	-0.00976	-0.08184	0.09467	0.03984	0.07805	-0.72183	-0.10757	0.55604
16	0.11873	-0.01853	0.09222	0.81714	0.08670	-0.08901	0.06204	0.70995
17	0.20040	-0.04991	0.58914	0.26001	0.04532	0.09107	-0.09346	0.47642

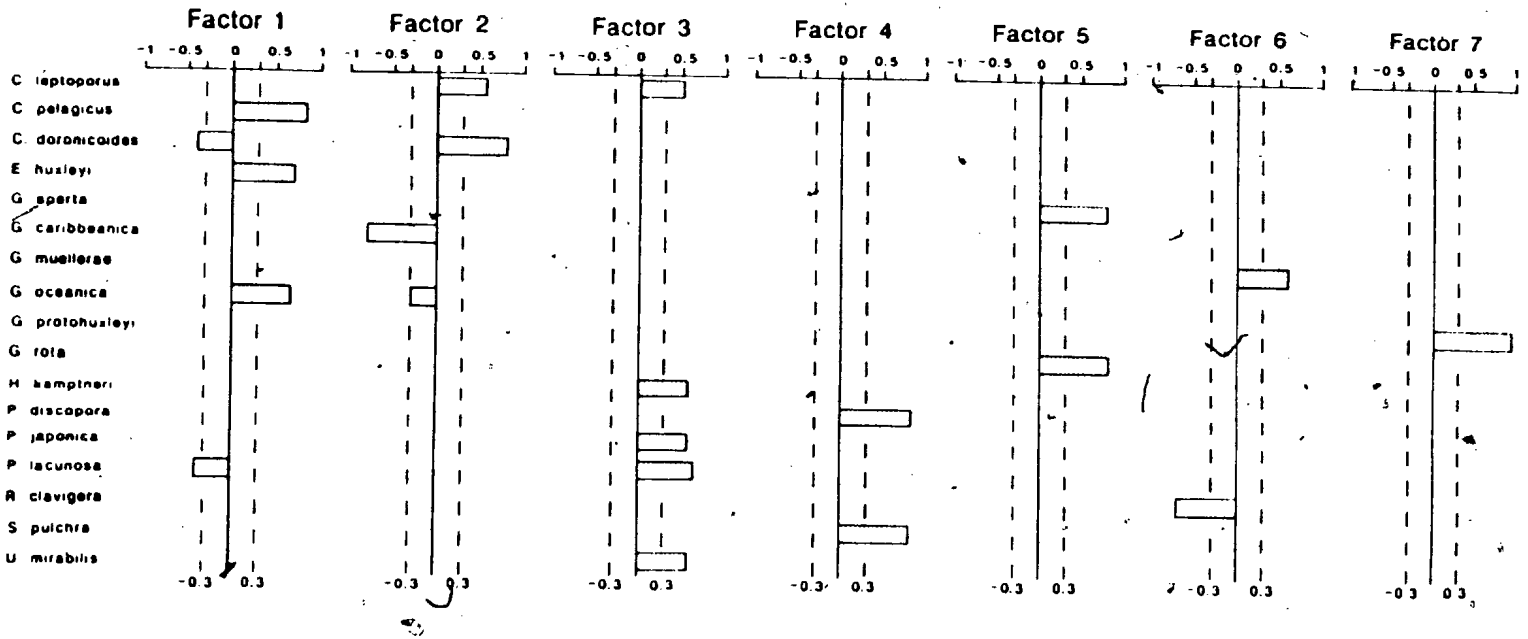


Fig. 7.6. Major factor loadings of the floral species on the extracted factors.

the variation pertaining to each species mentioned is not represented in the loading values of the extracted factors. C. leptoporus, E. huxleyi, P. lacunosa and R. clavigera are also low in communality values ranging from 0.53 to 0.59. The other variables have relatively high communality values ranging up to 0.87.

The extracted seven factors account for 63.4% of the total variance within the variables through the interval under study. For the purpose of interpreting the extracted factors, only the variables with a factor loading above 0.3 in positive relationships and below -0.3 in negative relationships are selected to define each factor because 0.3 is commonly used as a cutoff level for orthogonal factor loadings (Comrey, 1973).

Factor 1 accounts for 14.4% of the variance, and is defined by positive loadings of C. pelagicus, E. huxleyi and G. oceanica and by negative loadings of C. doronicoides and P. lacunosa. The internally reciprocal relationship between C. pelagicus and G. oceanica was not recognized in R-mode factor analysis either. Presumably, the internal relationship between the two species was masked by a strong first order cycle i.e., abundant occurrences of both species in the upper part of the stratigraphic interval under study. Although the positive loadings of the first three species can be assigned to a stratigraphic component, the possible existence of environmental signal cannot be eliminated because C. pelagicus and E. huxleyi (cold variety) can be considered as the most probable signal for the cold Labrador Current; G. oceanica as a signal for the warm Gulf Stream-North Atlantic Drift. It is noticeable that the positive relationship between the first three species corresponds to cluster group 1 of R-mode cluster analysis. The negative loadings of C. doronicoides and P. lacunosa are assigned to a stratigraphic component because the two species occur abundantly in the lower part of the stratigraphic section. Therefore, this factor is interpreted to reflect a stratigraphic signal, but with a possible environmental signal.

Factor 2 accounts for 12.2% of the variance and it is loaded positively by C. leptoporus and C. doronicoides and negatively by G. caribbeanica and G. oceanica. There is a strong stratigraphic signal because C. doronicoides is abundant in the lower part of the section, whereas G. caribbeanica and G. oceanica are abundant in the upper part of the section. Considering that G. caribbeanica and G. oceanica are internally reciprocal in abundance, the negative loading by the two species is another example for that the internal relationship between the two species was masked by a strong first order cycle. It is noticeable that all the component species of this factor are solution-resistant forms. Therefore, this factor may be interpreted to reflect a dissolution signal superimposed on a stratigraphic signal.

Factor 3 accounts for 10.6% of the variance. The factor is positively loaded by C. leptoporus, H. kamptneri, P. japonica, P. lacunosa and U. mirabilis. The positive loading by P. lacunosa indicates that this factor has a stratigraphic component because the species occurs only in the lower part of the section. The other component species of this factor represent a warm water signal, probably the influence of subtropical water-mass (McIntyre and Bé, 1967).

Factor 4 accounts for 7.3% of the variance. The factor is positively loaded by P. discopora and S. pulchra. Because the two species are relatively well preserved in this study despite their susceptibility to dissolution (McIntyre and McIntyre, 1971), the loading by these species may be interpreted as a hemipelagic signal (Gartner et al., 1987). It is interesting to note that this factor group corresponds to cluster group 4 of R-mode cluster analysis.

Factor 5 accounts for 6.7% of the variance. The factor is positively loaded by G. aperta and G. rota. The strong positive loading by the two small size

coccolith species may be interpreted as a productivity signal (Gartner et al., 1983, 1987; Gartner, 1988). This factor group also corresponds to cluster group 3 of R-mode cluster analysis.

Factor 6 accounts for 6.2% of the variance. The factor is loaded positively by G. muellerae and negatively by R. clavigera. The inverse relationship between the two species is probably due to the difference in stratigraphic range between the two species resulting from the scattered occurrence of G. muellerae in the lower part and the scattered occurrence of R. clavigera in the upper part of the section.

Factor 7 accounts for 6.0% of the variance. The factor is loaded only by G. protohuxleyi. This factor is attributed to a stratigraphic component because the species occurs only in the middle of the section in a small percentage. However, the strong loading by only a single variable may be the result of "tail effect" which often occurs in case where more than optimum number of factors are retained (Gartner et al., 1987).

CHAPTER 8

SUMMARY AND CONCLUSIONS

The taxonomy and biostratigraphy of coccoliths from ODP Site 647 Hole B were carried out. Pleistocene paleoclimatic and paleoceanographic history of the Labrador Sea was reconstructed.

8.1. TAXONOMY AND BIOSTRATIGRAPHY

A total of 18 species was identified and classified systematically. Based on the occurrences of the FAD of E. huxleyi and the LAD of P. lacunosa at 11.1m (647B-2H-3, 19-25cm) and 21.8m (647B-3H-3, 120-125cm), respectively, the studied interval was assigned to the upper three zones of Martini's (1971) Standard Zonation i.e., 0 to 11.1m = E. huxleyi Zone (NN 21); 11.1 to 21.8m = G. oceanica Zone (NN 20); and 21.8 to 56m = the upper part of P. lacunosa Zone (NN 19).

8.2. PALEOECOLOGY

The preservation state of the observed coccoliths was relatively good throughout the studied interval; however, a few placoliths, cyrtoliths and caneoliths show evidence of partial dissolution. This probably indicates that the sea-floor bathymetry of Site 647 has been located within the oligolytic zone above the CCD during the studied interval. Although the observed coccolith assemblages tend to be dominated by solution resistant forms, the good preservation state of fragile species (e.g., Pontosphaera sp.) suggests that

dissolution was not too strong to obliterate the environmental signals of the floral assemblages.

Comparison of the floral and the oxygen isotopic data showed that in general, glacial stages are characterized by low floral and faunal abundances suggesting minimum productivity in the southern Labrador Sea whereas interglacial stages are characterized by high floral and faunal abundances suggesting maximum productivity in that area. However, relatively high floral and faunal abundances have been observed during the early phases of glacial stages 6, 8, 12, 20, 22 and 24. The observed high abundances may indicate that primary biological productivity remained high in the southern Labrador Sea during the early phases of the glacial stages perhaps due to northward advection of warm North Atlantic water. The barren of coccoliths and abrupt decrease in planktonic foraminifera in the glacial to interglacial transitional intervals (e.g., stages 20/19, 18/17 and 12/11) suggest that biogenic carbonate productivity may have been suppressed by the input of low-salinity and low-nutrient melt waters during deglaciation. However, the lithofacies-laminated detrital carbonate (facies C) in the transitional interval 12/11; terrigenous silty clays (facies A) in the other transitional intervals - indicate that the coccolith barren zones may have been caused by dilution by terrigenous sediments.

Downcore variations in relative abundances of the observed coccoliths were used as a primary source for the reconstruction of the Pleistocene paleoclimatic and paleoceanographic history of the Labrador Sea. The preliminary investigation of the downcore data has led to the following conclusions:

i) The internally reciprocal relationship between the cold water species, C. pelagicus and the warm water species, G. oceanica during the oxygen isotopic stages 1 to 7 is interpreted to reflect possible interactions between the cold Labrador Current and the warm North Atlantic Drift. The dominant occurrence

of E. huxleyi and C. pelagicus and the minor occurrence of G. oceanica in the uppermost part of oxygen isotopic stage 1 is also interpreted to reflect an increasing role of the Labrador Current in the surface circulation patterns of the Labrador Sea.

ii) The reciprocal relationship between G. oceanica and G. caribbeanica is considered to have been controlled by either interactions between warm and cool water-masses or phylogenetic lineage between the two species or by both.

iii) The mutual exclusion or reciprocal relationship between G. caribbeanica and C. doronicoides is considered to have been controlled by phylogenetic lineage between the two species.

iv) No apparent preference for glacial or interglacial stages is observed among the identified coccolith species.

The reconstructed surface water-mass history of the southern Labrador Sea, primarily based on coccolith assemblages can be summarized as follows:

i) The stratigraphic interval from 0 to ca. 0.472 Ma (oxygen isotopic stages 1 to 12/13) is dominated by subpolar and transitional water-masses, whereas the other interval from ca. 0.472 to ca. 1.076 Ma (stages 12/13 to 35/36) is dominated by transitional water-masses.

ii) The presence of polar water-mass during the late phase of glacial stage 2 is interpreted to reflect an increased influence of the cold Labrador Current and southward migration of polar front.

iii) The early phases of several glacial stages, particularly 2, 4, 6, 8, 10, 12, 14, 20, 24 are characterized by the presence of transitional or subpolar water-masses which probably indicates northward advection of warm North Atlantic water.

iv) In general, the water-mass history of the southern Labrador Sea based on coccolith assemblages bears warmer signals than that based on planktonic foraminifera (cf. Aksu et al., in press).

The overwhelming dominance of C. doronicoides below oxygen isotope stage 25 in Hole 647B, which shows a good correlation with the mid-Pleistocene small Gephyrocapsa dominance interval in low latitude oceanic cores (Gartner, 1988), might be an important paleoceanographic marker in relation to the mid-Pleistocene shift in climatic periodicities from 41,000 years to 100,000 years.

8.3. MULTIVARIATE PALEOECOLOGICAL ANALYSIS

Because the species associations or groupings recognized by R-mode cluster and factor analysis were interpreted primarily based on the presently available ecological characteristics of the component species, all the interpretations attempted in this study should be considered as tentative ones. The noticeable results from R-mode analysis can be summarized as follows:

i) The grouping of C. pelagicus, E. huxleyi and G. oceanica is interpreted to reflect possible interactions between the cold Labrador Current and the warm North Atlantic Drift or coexistence of the two contrasting currents at the southern Labrador Sea during the studied interval.

ii) G. aperta and G. rota may have been grouped together due to the similar productivity response of the two species.

iii) The grouping of P. discopora and S. pulchra is considered to reflect three different signals i.e., dissolution, hemipelagic influence and warm water influence.

Q-mode cluster analysis classified the studied interval into three major groups based on the similarity of the floral assemblages. Cluster group A is distributed above the oxygen isotopic stage 7. The floral assemblage of cluster group A characterizes a relatively cool paleoceanographic trend during the interval. Cluster group B is distributed between the oxygen isotopic stage 8 and the stage 25. Cluster group C is distributed below the oxygen isotopic stage 25. The boundary between cluster group B and cluster group C is placed slightly above the top of Jaramillo magnetic event, ca. 0.91 Ma (Srivastava, Arthur, Clement et al., 1987). Although the boundary is considered to have been controlled primarily by the possible phylogenetic change from C. doronicoides to G. caribbeanica, it is inferred that the evolutionary event may have been triggered by any significant paleoceanographic change, perhaps resulting from the causes of the shift in the climatic response of the North Atlantic Ocean (i.e., from 41,000 years to 100,000 years in dominant periodicity) during the mid-Pleistocene ca. 0.9 to 0.6 Ma (Ruddiman, Backman et al., 1987).

8.4. RECOMMENDATIONS FOR FURTHER RESEARCH

Spectral analysis of coccolith abundances will help to explore the possible links between the Milankovitch orbital cycles and the causes of the floral abundance variations. The results from the analysis will be particularly helpful for time-series paleoceanographic interpretation of the study area. In addition, the results will contribute to regional paleoceanographic study of the high latitude North Atlantic Ocean.

REFERENCES

Aksu, A.E., 1983. Holocene and Pleistocene dissolution cycles in deep-sea cores of Baffin Bay and Davis Strait : paleoceanographic implications. Marine Geology, 53 : 331-340

Aksu, A.E. and Mudie, P.J., 1985. Late Quaternary stratigraphy and paleoecology of northwest Labrador Sea. Marine Micropaleontology, 9 : 537-557.

Aksu, A.E. et al., in press. High resolution foraminiferal, palynological and stable isotopic records of Upper Pleistocene sediments from the Labrador Sea : paleoclimatic and paleoceanographic trends. In : Srivastava, S.P., Arthur, M., Clement, B. et al., in press. ODP Leg 105 (part B).

Alam, M. et al., 1983. Late Quaternary stratigraphy and paleo-oceanography of the Grand Banks continental margin, eastern Canada. Boreas, 12 : 253-261.

Arrhenius, G., 1952. Sediment cores from the East Pacific. Rep. Swed. Deep Sea Exped. (1947-1948), 5 : 1-89.

Bartolini, C., 1970. Coccoliths from sediments of the western Mediterranean. Micropaleontology, 16 : 129-154.

Berger, W.H., 1973. Deep-sea carbonates : evidence for a coccolith lysocline. Deep-Sea Research, 20 : 917-921.

Berggren, W.A. and Hollister, C. D., 1977. Plate tectonics and paleocirculation - commotion in the ocean. Tectonophysics, 38 : 11-48.

Black, M., 1968. Taxonomic problems in the study of coccoliths. Paleontology, 11 : 793-813.

Black, M. and Barnes, B., 1961. Coccoliths and discoasters from the floor of the South Atlantic Ocean. J. Roy. Microscop. Soc., 80 : 137-147.

Boudreaux, J. E. and Hay, W. W., 1969. Calcareous Nannoplankton and Biostratigraphy of the late Pliocene - Pleistocene - Recent sediments in the Submarex Cores. Revista Esp. Micropaleont., 1 : 249-292.

Bukry, D., 1972. Further comments on coccolith stratigraphy, Leg 12, Deep Sea Drilling Project. In : Laughton, A.S., Berggren, W.A., et al., Init. Repts. DSDP, 12 : 1071-1083.

Bukry, D., 1973. Coccolith stratigraphy, eastern equatorial Pacific, Leg 16, DSDP. In : van Andel, T.H., Heath, G.R. et al., Initial Reports of the DSDP, 16, U.S. Government Printing Office, Washington D.D., pp. 653-711.

Bukry, D., 1975. Coccolith and silicoflagellate stratigraphy, northwestern Pacific Ocean, DSDP Leg 32. In : Larson, R.L., Moberly, R. et al., Initial Reports of the DSDP, 32, U.S. Government Printing Office, Washington D.C., pp. 677-701.

Bukry, D. and Bramlette, M.N., 1969. Some new and stratigraphically useful calcareous nannofossils of the Cenozoic. Tulane Studies in Geology and Paleontology, 7 : 131-142.

Bulfinch, D.L. et al., 1982. The high velocity core of the Western Boundary Undercurrent at the base of the U.S. continental rise. Science, 215: 970-973.

Cattell, R.B., 1978. The scientific use of factor analysis in behavioral and life sciences. Plenum Press, New York, N.Y., 618 pp.

Chough, S.K., 1978. Morphology,. sedimentary facies and processes of the northwest Atlantic mid-ocean channel between 61° and 52°N, Labrador Sea. Thesis, McGill Univ., Quebec, 167 pp.

CLIMAP Project Members, 1976. The surface of the ice age earth. Science, 191 : 1131-1137.

Coachman, L.K. and Aagaard, K., 1974. Physical oceanography of arctic and subarctic seas. In: Herman, Y. (ed.), Marine Geology and Oceanography of the Arctic Seas. Springer, New York, 1-72.

Comrey, A.L., 1973. A first course in factor analysis. Academic Press, New York, N.Y., 316 pp.

Crowley, T.J., 1984. Atmospheric circulation patterns during glacial inceptions- a possible candidate. Quaternary Research, 21: 105-110.

Davis, J.C., 1973. Statistics and data analysis in geology. John Wiley & Sons, Inc., New York, 550 pp.

Dean, W.E. and Gardner, J.V., 1986. Milankovitch cycles in Neogene deep-sea sediment. Paleoceanography, 1 : 539-553

Denton, G.H. and Hughes, T.J., 1983. Milankovitch theory of ice ages: hypothesis of ice-sheet linkage between regional insolation and global climate. Quaternary Research, 20: 125-144.

de Vernal, A. and Hillaire-Marcel, C., 1987a. Paleoenvironments along the eastern Laurentide ice sheet margin and timing of the last ice maximum and retreat. Géographie Physique et Quaternaire, 41: 265-277.

de Vernal, A. and Hillaire-Marcel, C., 1987b. Elements d'une climatostratigraphie du Pleistocene moyen et tardif dans l'est du Canada par l'analyse palynologique et isotopique du forage 84-030-003, mer du labrador. Canadian Journal of Earth Sciences, 24 : 1886-1902.

Dodd, J.R. and Stanton, R.J., 1981. Paleoecology, Concepts and Applications. Wiley. New York, N.Y., 559 pp

Feldhausen, P.H. and Ali, S.A., 1974. A multivariate statistical approach to sedimentary environmental analysis. Trans. Gulf Coast Assoc. Geol. Soc., 24 : 314-320.

Feldhausen, P.H. and Ali, S.A., 1976. Sedimentary environmental analysis of Long Island Sound, U.S.A. with multivariate statistics. In : Merriam, D.F. (ed.), Quantitative techniques for the analysis of sediments. Pergamon Press. Oxford : 73-98.

Fillon, R.H., 1985. Northwest Labrador Sea stratigraphy, sand input and paleoceanography during the last 160,000 years. In : Andrews, J.T. (ed.), Quaternary environments eastern Canadian Arctic, Baffin Bay and West Greenland, Allen and Unwin, Boston, 210-247.

Fillon, R.H. and Aksu, A.E., 1985. Evidence of subpolar water masses in Baffin Bay and labrador Sea during isotopic stage 2. Ibid, 248-262.

Fillon, R.H. and Duplessy, J.C., 1980. Labrador Sea bio-, tephro-, oxygen isotopic stratigraphy and Late Quaternary paleoceanographic trends. Can. J. Earth Sci., 17 : 831-854.

Fillon, R.H. et al., 1981. Terrigenous sand in Labrador Sea sediments and paleoglacial events on Baffin Island over the last 100,000 years. Boreas, 10 : 107-124.

Firth, J., et al., in press. Coccolith biostratigraphy of ODP Leg 105 (title to be identified). In: ODP Leg 105 Initial Reports, Part B.

Gard, G., 1986. Calcareous nannofossil biostratigraphy of late Quaternary Arctic sediments. Boreas, 15: 217-229.

Gard, G., 1988. Late Quaternary calcareous nannofossil biozonation, chronology and palaeo-oceanography in areas north of the Faeroe-Iceland ridge. Quaternary Science Reviews, 7: 65-78.

Gardner, J.V., 1982. High-resolution carbonate and organic-carbon stratigraphies for the late Neogene and Quaternary from the western Caribbean and eastern equatorial Pacific. In : Prell, W.L., Gardner, J.V., et al., Init. Repts. DSDP, 68 : 347-364.

Gartner, S., 1969. Correlation of Neogene planktonic foraminifer and calcareous nannofossil zones. Trans. Gulf Coast Assoc. Geol. Soc., 19 : 585-599.

Gartner, S., 1972. Late Pleistocene Calcareous Nannofossils in the Caribbean and their interoceanic correlation. Paleogeography, paleoclimatology, paleoecology, 12 : 169-191.

Gartner, S., 1977a. Calcareous nannofossil biostratigraphy and revised zonation of the Pleistocene. Mar. Micropaleontol., 2 : 1-25.

Gartner, S., 1977b. Nannofossils and Biostratigraphy : An Overview. Earth-Science Reviews, 13 : 227-250.

Gartner, S., 1980. Paleoceanographic implications of the dominance of small Gephyrocapsa in the mid-Pleistocene nannoflora. Geo. Soc. Am. 1980 Ann. Meeting, Abstracts with Program, 12(7) : 432.

Gartner, S. and Emiliani, C., 1976. Nannofossil biostratigraphy and climatic stages of the Brunhes Epoch. Bull. Ame. Asso. Petro. Geol., 60 : 1562-1564

Gartner, S., Chen, M.P., and Stanton, R.J., 1983. Late Neogene Nannofossil Biostratigraphy and Paleoceanography of the Northeastern Gulf of Mexico and adjacent areas. Marine Micropaleontology, 8 : 17-50.

Gartner, S., Chow, J., and Stanton, R.J., 1987. Late Neogene Paleoceanography of the eastern Caribbean, the Gulf of Mexico, and the eastern Equatorial Pacific. Marine Micropaleontology, 12 : 255-304.

Gartner, S., 1988. Paleoceanography of the mid-Pleistocene. Marine Micropaleontology, 13: 23-46.

Geitzenauer, K.R., 1969. Coccoliths as late Quaternary paleoclimatic indicators in the subantarctic Pacific Ocean. Nature, 223 : 170-172.

Geitzenauer, K.R., 1972. The Pleistocene calcareous nannoplankton of the subantarctic Pacific Ocean. Deep-Sea Res., 19 : 45-60.

Geitzenauer, K.R., Roche, M.B. and McIntyre, A., 1976. Modern Pacific Coccolith Assemblages : Derivation and Application to Late Pleistocene Paleotemperature Analysis. In : Cline, R.M. and Hays, J.D. (eds.), Investigation of Late Quaternary Paleoceanography and Paleoclimatology. Geol. Soc. Am. Mem., 145 : 423-448.

Geitzenauer, K.R., Roche, M.B. and McIntyre, A., 1977. Coccolith biogeography from North Atlantic and Pacific surface sediments. In : Ramsay, A.T.S. (ed.), Oceanic Micropaleontology. Academic Press, New York, pp. 973-1008.

Gevirtz, J.L. et al., 1971. Paraecology of benthonic foraminifera and associated micro-organisms of the continental shelf off Long Island, New York, Jour. Paleontology, 45 : 153-177.

Haq, B.U., 1978. Calcareous Nannoplankton. In: Haq, B.U. and Boersma, A. (eds.), Introduction to Marine Micropaleontology, Elsevier, New York, pp. 79-107.

Harbaugh, J.W. and Merriam, D.F., 1968. Computer applications in stratigraphic analysis. John Wiley & Sons, Inc., New York, 282p.

Hay, W.W., 1977. Calcareous Nannofossils. In : Ramsay, A.T.S. (ed.), Oceanic Micropaleontology, Academic Press, London, pp. 1055-1200.

Hay, W.W., Mohler, H.P., Roth, P.H., Schmidt, R.R. and Boudreaux, J.E., 1967. Calcareous nannoplankton zonation of the Cenozoic of the Gulf Coast and Caribbean Antillean area and transoceanic correlation. Trans. Gulf Coast Assoc. Geol. Soc., 17 : 428-480.

Hays, J.D., Imbrie, J., and Shackleton, N.J., 1976. Variations in the Earth's orbit : pacemaker of the ice ages. Science, 194 : 1121-1131.

Hedberg, H.D. (edt.), 1976. International Stratigraphic Guide : A Guide to Stratigraphic Classification, Terminology, and Procedure. International Subcommission on Stratigraphic Classification of IUGS Commission on Stratigraphy, John Wiley & Sons, New York, 200 pp.

Heezen, B.C. et al., 1966. Shaping of the continental rise by geostrophic contour currents. Science, 152: 502-508.

Honjo, S., 1977. Biogeography and provincialism of living coccolithophorids in the Pacific Ocean. In : Ramsay, A.T.S. (ed.), Oceanic Micropaleontology. Academic Press, New York, pp. 951-972.

Honjo, S. and Okada, H., 1974. Community structure of coccolithophores in the photic layer of the mid-Pacific. Micropaleontology, 20 : 209-230.

Hsü, K.J. and Anderson, J.E., 1970. Lithology. In : Maxwell, A.E. et al., Initial Reports of DSDP, 3 : 445-453.

Imbrie, J. and Purdy, E.G., 1962. Classification of modern Bahamian carbonate sediments. In : Ham, W.E. (ed.), Classification of carbonate rocks : a symposium. AAPG Memoir 1 : 253-272.

Imbrie, J. and Kipp, N., 1971. A new micropaleontological method for quantitative paleoclimatology : Application to a late Pleistocene Caribbean core. In : Turekian, K.K. (ed.), The late Cenozoic glacial ages. New Haven, Conn., Yale Univ. Press, pp. 71-181.

Imbrie, J. and Imbrie, J.Z., 1980. Modelling the climatic response to orbital variations. Science, 207 : 943-953.

Ivers, W.D., 1975. The deep circulation in the North Atlantic with especial reference to the Labrador Sea. Thesis, Univ. California, San Diego, CA, 179 pp.

Kaesler, R.L., 1966. Quantitative re-evaluation of ecology and distribution of recent foraminifera and ostracoda of Todos Santos Bay, Baja California, Mexico. The Univ. of Kansas Paleontological Contributions, 19 : 1-50.

Kellogg, T.B., 1977. Paleoclimatology and Paleo-oceanography of the Norwegian and Greenland Seas : the last 450,000 years. Marine micropaleontology, 2 : 235-249.

Klovan, J.E., 1966. The use of factor analysis in determining depositional environments from grain-size distributions. Jour. Sedimentary Petrology, 36 : 115-125.

Laughton, A.S., 1972. The southern Labrador Sea - A key to the Mesozoic and

early Tertiary evolution of the North Atlantic. In : Laughton, A.S., Berggren, W.A., et al., Initial reports of the DSDP, 12, Washington, pp. 1155-1180.

Lazier, J.R.N., 1973. The renewal of Labradbr Sea Water. Deep-Sea Research, 20 : 341-353.

Loeblich, A.R., Jr. and Tappan, H., 1966-1973. Annotated Index and Bibliography of the Calcareous Nannoplankton. Phycologia, 5 : 81-216 (1966); J. Paleontol., 42 : 584-593 (1968); J. Paleontol., 43 : 568-588 (1969); J. Paleontol., 44 : 558-574 (1970); Phycologia, 9 : 157-174 (1970); Phycologia, 10 : 309-339 (1972); J. Paleontol., 47 : 714-759 (1973).

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. Proc. 2nd Planktonic Conference, Rome, 1970. 2 : 739-785.

McIntyre, A. and Bé, A.W.H., 1967. Modern coccolithophoridae of the Atlantic Ocean - I. Placoliths and Cyrtoliths. Deep-Sea Research, 14 : 561-597.

McIntyre, A., Bé, A.W.H., and Preikstas, R., 1967. Coccoliths and the Pliocene - Pleistocene boundary. Progress in Oceanography, 4 : 3-24.

McIntyre, A., Bé, A.W.H. and Roche, M.B., 1970. Modern Pacific Coccolithophorida : A Paleontological Thermometer. Trans. N.Y. Acad. Sci., 32 : 720-731.

McIntyre, A. and McIntyre, R., 1971. Coccolith concentrations and differential solution in oceanic sediments. In : Funnel, B. and Riedel, W.R. (eds.), The Micropaleontology of Oceans, Cambridge Univ. Press, pp. 253-261.

McIntyre, A., Ruddiman, W.F., and Jantzen, R., 1972. Southward penetrations of the North Atlantic Polar Front : faunal and floral evidence of large-scale

surface water mass movements over the last 225,000 years. Deep-Sea Research, 19 : 61-77.

Milankovitch, M.M., 1941. Canon of insolation and the ice-age problem. Beograd, Koniglich Serbische Akademie. English Translations, published for the U.S. Department of Commerce and the National Science Foundation, Washington D.C.

Mudie, P.J. and Aksu, A.E., 1984. Paleoclimate of Baffin Bay from 300,000-year record of foraminifera, dinoflagellates and pollen. Nature, 312 : 630-634.

Okada, H. and Honjo, S., 1973. The distribution of oceanic coccolithophorids in the Pacific. Deep-Sea Research, 20 : 355-374.

Okada, H. and McIntyre, A., 1979. Seasonal distribution of modern coccolithophores in the Western North Atlantic Ocean. Marine Biology, 54: 319-328.

Okada, H. and Bukry, D., 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). Marine Micropaleontology, 5 : 321-325.

Park, R.A., 1974. A multivariate analytical strategy for classifying paleoenvironments. Mathematical Geology, 6 : 333-352.

Parks. J.M., 1966. Cluster analysis applied to multivariate geologic problems. Jour. Geology, 74 : 703-715.

Perch-Nielsen, K., 1972. Remarks on late Cretaceous to Pleistocene coccoliths from the North Atlantic. In : Laughton, A.S., Berggren, W.A., et al., Init. Repts. DSDP, 12 : pp. 1003-1069.

Perch-Nielsen, K., 1985. Cenozoic calcareous nannofossils. In : Bolli, H.M., Saunders, J.B. and Perch-Nielsen, K. (eds.), Plankton Stratigraphy. Cambridge University Press, pp. 427-554.

Pickard, G.L. and Emery, W.J., 1982. Descriptive Physical Oceanography: An Introduction. 4th edition, Pergamon Press, Oxford, pp. 249.

Purdy, E.G., 1963. Recent calcium carbonate facies of the Great Bahama Bank, 1. Petrography and reaction groups. Jour. Geology, 71 : 334-355.

Ramsay, A.T.S., 1972. Aspects of the distribution of fossil species of calcareous nannoplankton in North Atlantic and Caribbean sediments. Nature, 236 : 67-70.

Roche, M.B., McIntyre, A., and Imbrie, J., 1975. Quantitative paleoceanography of the Late Pleistocene - Holocene North Atlantic : coccolith evidence. In : Saito, T. and Burckle, L. (eds.), Late Neogene Epoch Boundaries. Micropaleontology Spe. Pub. No. 1, pp. 199-224.

Romesburg, H.C., 1984. Cluster analysis for researchers. Lifetime Learning Publications, London, 334 pp.

Roth, P.H., 1973. Calcareous Nannofossils - Leg 17, Deep Sea Drilling Project. In : Winterer, E.L., Ewing, J.I., et al., Init. Repts. DSDP, 17, Washington, U.S. Govt. Printing Office, pp. 695-975.

Roth, P.H. and Berger, W.H., 1975. Distribution and dissolution of coccoliths in the south and central Pacific. In : Sliter, W.V., Be, A.W.H. and Berger, W.H. (eds.), Dissolution of deep-sea carbonates. Cushman Foundation for Foraminiferal Research Spe. Pub. No. 13, pp. 87-113.

Roth, P.H. and Coulbourn, W.T., 1982. Floral and solution patterns of coccoliths in surface sediments of the North Pacific. Marine Micropaleontology, 7 : 1-52.

Ruddiman, W.F. and McIntyre, A., 1976. Northeast Atlantic paleoclimatic changes over the past 600.000 years. In: Cline, R.M. and Hays, J.D. (eds.), Investigation of late Quarternary paleoceanography and paleoclimatology. Geol. Soc. Am. Memo. 145: 111-146.

Ruddiman, W.F. and McIntyre, A., 1977. Late Quaternary surface ocean kinematics and climatic change in the high-latitude North Atlantic. Jour. geophysic. Res., 82 : 3877-3887.

Ruddiman, W.F. and McIntyre, A., 1979. Warmth of the subpolar North Atlantic Ocean during Northern Hemisphere ice-sheet growth. Science, 204 : 173-175.

Ruddiman, W.F. and McIntyre, A., 1981a. Oceanic mechanism for amplification of the 23,000-year ice volume cycle. Science, 212 : 617-627.

Ruddiman, W.F. and McIntyre, A., 1981b. The North Atlantic Ocean during the last deglaciation. Paleogeography, Paleoclimatology, Paleoecology, 35 : 145-214.

Ruddiman, W.F. and McIntyre, A., 1984. Ice-age thermal response and climatic role of the surface Atlantic Ocean, 40°N to 63°N. G.S.A. Bull., 95 : 381-396.

Ruddiman, W.F. et al., 1980. Oceanic evidence for the mechanism of rapid Northern Hemisphere glaciation. Quaternary Research, 13 : 33-64.

Ruddiman, W.F., Raymo, M., and McIntyre, A., 1986. Matuyama 41,000-year cycles : North Atlantic Ocean and northern hemisphere ice sheets. Earth and Planetary Science Letters, 80 : 117-129.

Ruddiman, W.F., Backman, J. et al., 1987. Leg 94 Paleoenvironmental Synthesis. In: Ruddiman, W.F., Kidd, R.B., Thomas, E. et al., Initial Reports of DSDP, 94, Washington, U.S. Govt. Printing Office, pp. 1207-1215.

Rummel, R.J., 1970. Applied factor analysis. Northwestern Univ. Press, Evanston, 617 pp.

Samtleben, C., 1980. Die Evalution der Coccolithophoriden-Gattung Gephyrocapsá nach Befunden im Atlantik. Palaont. Z., 54 : 91-127.

Schneidermann, N., 1973. Deposition of coccoliths in the compensation zone of the Atlantic Ocean. In : Smith, L.A. and Hardenbol, J. (eds.), Proc. Symposium on Calcareous Nannofossils, Gulf Coast Section, SEPM, Houston, Texas, pp. 140-151.

Schneidermann, N., 1977. Selective dissolution of Recent coccoliths in the Atlantic Ocean. In : Ramsay, A.T.S. (ed.), Oceanic Micropaleontology, Academic Press, New York, N.Y., pp. 1009-1053.

Shackleton, N.J. and Opdyke, N.D., 1976. Oxygen-isotope and paleomagnetic stratigraphy of Pacific core V28-239 late Pliocene to latest Pleistocene. In: Cline, R.M. and Hays, J.D. (eds.), Investigation of late Quaternary paleoceanography and paleoclimatology. Geol. Soc. Am. Memo. 145: 449-464.

Sneath, P.H.A. and Sokal, R.R., 1973. Numerical taxonomy. Freeman, San Francisco, 573 pp.

SPSS User's Guide, 1988. 3rd edition. SPSS Inc., Chicago, 1072 pp.

Srivastava, S.P., Arthur, M., Clement, B. et al., 1987. Pro., Init. Repts. (Pt. A), ODP Leg 105, 917 pp.

Stanley, D.J. et al., 1981. Current-influenced depositional provinces, continental margin off Cape Hatteras, identified by petrologic method. Marine Geology, 40: 215-235.

Steinmetz, J.C. and Stradner, H., 1984. Cenozoic Calcareous Nannofossils from Deep Sea Drilling Project Leg 75, Southeast Atlantic Ocean. In : Hay, W.W., Sibuet, J.C., et al., Init: Repts. DSDP, 75, Washington, U.S. Govt. Printing Office, pp. 671-753.

Takayama, T. and Sato, T., 1987. Coccolith biostratigraphy of the North Atlantic Ocean, Deep Sea Drilling Project Leg 94. In : Ruddiman, W.F., Kidd, R.B., Thomas, E., et al., Init. Repts. DSDP, 94 : pp. 651-702.

Thierstein, H.R., Geitzenauer, K.R., Molfino, B. and Shackleton, N.J., 1977. Global synchroneity of late Quaternary coccolith datum levels : Validation by oxygen isotopes. Geology, 5 : 400-404.

Vernekar, A.D., 1972. Long-period global variations of incoming solar radiation. Meteorological Monographs, 12(34) : 1-10.

Wang, P. and Samtleben, C., 1983. Calcareous Nannoplankton in surface sediments of the East China Sea. Marine Micropaleontology, 8 : 249-259.

Williams, D.F., Moore, W.S. and Fillon, R.H., 1981. Role of glacial Arctic Ocean ice sheets in Pleistocene oxygen isotope and sea level records. Earth and Planetary Science Letters, 56 ; 157-166.

Wiseman. J.D.H., 1965 The changing rate of calcium carbonate sedimentation on the equatorial Atlantic floor and its relation to continental Late Quaternary stratigraphy. Rep. Swed. Deep-Sea Exped. (1947-1948), 7 : 289-354.

APPENDIX I

COCCOLITH CENSUS DATA

* Note: The first six samples are from Hudson 84-030-003G. Oxygen isotope data are from Aksu et al. (in press).

DEPTH (cm)	TOTAL no.	LEPTO %	PELAG %	DORON %	HUXLE %	APERT %	CARIB %	MUELL %	OCEAN %	PROTO %	ROTA %	KAMPT %	DISCO %	JAPON %	LACUN %	CLAVI %	PULCH %	MIRAB %	OXYGEN %
0000	564	18.11	48.82	0.00	24.80	0.00	1.57	0.00	3.15	0.00	0.00	1.97	0.00	0.00	0.00	0.00	0.79	0.79	2.09
0020	267	26.60	50.74	0.00	5.42	0.00	2.46	0.00	11.82	0.00	0.00	2.96	0.00	0.00	0.00	0.00	0.00	0.00	2.67
0040	38	4.76	28.57	0.00	2.38	0.00	14.29	0.00	38.10	0.00	0.00	11.90	0.00	0.00	0.00	0.00	0.00	0.00	3.20
0060	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.19
0072	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.84
0110	82	22.34	37.23	0.00	3.19	0.00	0.00	0.00	35.11	0.00	0.00	2.13	0.00	0.00	0.00	0.00	0.00	0.00	3.86
0129	175	36.00	26.85	0.00	1.71	3.42	4.00	0.00	23.42	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00	4.00	3.45
0148	213	23.26	31.18	0.00	9.40	0.99	3.96	0.00	27.22	0.00	0.00	3.46	0.00	0.00	0.00	0.00	0.00	0.49	3.75
0170	64	15.53	28.15	0.00	5.82	0.97	7.28	0.00	41.26	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.48	3.71
0190	144	13.88	19.44	0.00	2.77	0.69	13.88	0.00	48.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69	3.62
0210	228	12.93	32.83	0.00	2.98	3.48	12.43	0.00	34.82	0.00	0.00	0.49	0.00	0.00	0.00	0.00	0.00	0.00	3.50
0230	296	5.71	3.33	0.00	0.47	4.76	24.76	0.00	60.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.73
0250	214	14.42	3.48	0.00	1.49	3.98	18.40	0.00	57.21	0.00	0.00	0.49	0.00	0.00	0.00	0.00	0.00	0.49	3.85
0280	371	8.65	15.38	0.00	3.84	4.32	11.53	0.00	54.32	0.00	0.00	1.44	0.00	0.00	0.00	0.00	0.00	0.48	3.11
0300	176	15.90	7.38	0.00	7.95	0.56	10.79	0.00	56.81	0.00	0.00	0.56	0.00	0.00	0.00	0.00	0.00	2.27	3.05
0320	273	9.26	19.02	0.00	2.92	0.97	9.26	0.00	53.17	0.00	0.00	2.92	0.00	0.00	0.00	0.00	0.00	2.43	3.26
0340	272	11.76	33.82	0.00	0.00	2.45	11.76	0.00	49.01	0.00	0.00	1.96	0.00	0.00	0.00	0.00	0.00	0.00	3.54
0360	588	14.00	13.00	0.00	2.00	2.00	10.00	0.00	51.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	4.00	3.16
0380	396	17.32	25.74	0.00	4.95	0.99	4.45	0.00	39.60	0.00	0.00	3.96	0.00	0.00	0.00	0.00	0.00	2.97	3.19
0400	556	6.00	30.00	0.00	5.00	0.00	12.00	0.00	43.00	0.00	0.00	3.50	0.00	0.00	0.00	0.00	0.00	0.50	3.77
0430	11	9.09	13.63	0.00	0.00	0.00	0.00	0.00	68.18	0.00	0.00	9.09	0.00	0.00	0.00	0.00	0.00	0.00	4.12
0450	46	16.24	51.28	0.00	2.56	0.00	0.00	0.00	27.35	0.00	0.00	1.71	0.00	0.00	0.00	0.00	0.00	0.85	3.89
0470	379	7.96	36.31	0.00	1.49	12.43	7.46	0.00	30.34	0.00	0.00	1.99	0.00	0.00	0.00	0.49	0.00	1.49	3.07
0490	209	8.86	25.61	0.00	1.97	3.94	5.91	0.00	51.72	0.00	0.00	0.49	0.00	0.00	0.00	0.00	0.49	0.98	2.80
0510	134	15.52	32.42	0.00	0.91	0.91	0.91	0.00	47.48	0.00	0.00	1.36	0.00	0.00	0.00	0.00	0.00	0.45	3.20
0530	148	11.96	23.44	0.00	3.34	2.87	0.00	0.47	52.63	0.00	0.00	2.87	0.00	0.00	0.00	0.00	0.47	1.91	2.95
0550	102	22.43	24.87	0.00	2.92	0.48	2.92	0.00	42.43	0.00	0.00	2.43	0.00	0.00	0.00	0.00	0.48	0.97	2.55
0580	166	26.92	10.09	0.48	2.40	2.88	2.40	0.00	53.36	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.96	2.94
0600	207	9.45	18.46	0.00	4.05	0.90	1.80	0.00	63.06	0.00	0.00	1.80	0.00	0.45	0.00	0.00	0.00	0.00	2.44
0620	344	10.59	4.60	0.00	0.92	4.14	3.22	0.00	73.73	0.00	0.00	2.30	0.00	0.00	0.00	0.00	0.00	0.46	2.65
0640	300	14.28	0.00	0.00	0.86	8.65	6.49	0.00	63.63	0.00	0.00	5.19	0.00	0.43	0.00	0.00	0.00	0.00	2.79
0660	245	10.90	4.26	0.00	2.36	16.58	3.79	0.00	57.34	0.00	0.00	4.73	0.00	0.00	0.00	0.00	0.00	0.00	2.15
0680	286	21.36	0.00	0.00	2.27	7.27	4.09	0.00	61.36	0.00	0.00	1.36	0.00	0.90	0.00	0.00	0.45	0.90	1.52
0700	297	17.07	0.97	0.00	0.97	12.68	4.39	0.00	61.46	0.00	0.00	2.43	0.00	0.00	0.00	0.00	0.00	0.00	2.91
0730	73	20.51	41.66	0.00	0.64	4.48	2.56	0.00	26.92	0.00	0.00	3.20	0.00	0.00	0.00	0.00	0.00	0.00	4.18
0751	17	13.79	10.34	0.00	0.00	6.89	0.00	0.00	62.06	0.00	0.00	6.89	0.00	0.00	0.00	0.00	0.00	0.00	4.14
0773	43	29.59	46.93	0.00	0.00	0.00	0.00	0.00	22.44	0.00	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.00	4.50
0810	37	18.84	28.98	0.00	0.00	0.00	0.00	0.00	52.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.27
0830	77	23.18	32.36	0.00	0.00	0.48	3.38	0.00	38.64	0.00	0.00	1.93	0.00	0.00	0.00	0.00	0.00	0.00	4.14
0850	161	27.96	33.17	0.00	0.47	0.00	3.79	0.00	33.64	0.00	0.00	2.84	0.00	0.00	0.00	0.00	0.47	0.47	4.25
0870	236	3.41	17.56	0.00	0.00	23.90	1.95	0.00	45.36	0.48	0.00	2.92	0.00	0.00	0.00	0.00	1.95	2.43	2.56
0890	19	28.00	12.00	0.00	0.00	4.00	8.00	0.00	48.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.11
0910	102	24.29	19.15	0.00	0.00	0.93	5.60	0.00	43.45	0.00	0.00	5.70	0.00	0.00	0.00	0.46	0.46	0.00	3.14
0930	142	11.21	6.07	0.00	0.46	1.86	7.47	0.00	71.02	0.00	0.00	1.86	0.00	0.00	0.00	0.00	0.00	0.00	3.41
0959	70	11.27	50.37	0.00	0.00	1.50	2.25	0.00	34.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.50
0980	125	18.06	27.75	0.00	0.00	0.00	17.62	0.00	35.24	0.00	0.00	0.44	0.00	0.44	0.00	0.00	0.44	0.00	4.15
1000	166	16.74	29.18	0.00	0.00	0.47	22.00	0.00	29.66	0.00	0.00	0.95	0.00	0.47	0.00	0.00	0.00	0.47	4.19

1020	59	20.51	32.47	0.00	0.00	0.85	17.94	0.00	25.64	0.00	0.00	2.56	0.00	0.00	0.00	0.00	0.00	0.00	2.34
1050	196	8.55	21.62	0.00	0.45	1.80	27.92	0.00	39.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.44
1070	52	15.73	28.08	0.00	0.00	0.00	21.34	0.00	33.70	0.00	0.00	1.12	0.00	0.00	0.00	0.00	0.00	0.00	3.12
1090	47	18.66	25.33	0.00	0.00	1.33	16.00	0.00	38.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.84
1110	97	9.34	14.95	0.00	0.46	4.20	24.76	0.00	40.65	0.00	0.00	5.14	0.00	0.00	0.00	0.00	0.00	0.46	2.53
1130	315	12.98	19.71	0.00	0.00	0.48	21.63	0.00	36.53	0.00	0.00	8.17	0.00	0.00	0.00	0.00	0.00	0.48	3.49
1150	214	14.81	19.90	0.00	0.00	0.46	25.00	0.00	35.18	0.00	0.00	4.62	0.00	0.00	0.00	0.00	0.00	0.00	4.06
1170	668	4.33	3.14	0.00	0.00	1.57	48.42	0.00	41.33	0.00	0.00	0.78	0.00	0.00	0.00	0.00	0.00	0.39	4.23
1190	575	3.91	6.52	0.00	0.00	3.47	59.13	0.00	26.52	0.00	0.00	0.43	0.00	0.00	0.00	0.00	0.00	0.00	3.28
1209	571	8.75	3,33	0.00	0.00	2.91	51.66	0.00	32.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	3.58
1230	448	4.13	8.26	0.00	0.00	2.89	44.62	0.00	39.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	4.04
1260	843	7.79	6.10	0.00	0.00	0.33	56.61	0.00	28.47	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	3.73
1280	1480	3.24	3.24	0.00	0.00	4.05	64.59	0.00	24.32	0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.00	4.08
1300	560	3.57	3.21	0.00	0.00	6.42	48.21	0.00	37.85	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.35	3.96
1320	625	4.40	7.60	0.00	0.00	1.20	72.00	0.00	13.20	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.40	0.00	3.80
1340	641	4.94	4.18	0.00	0.00	0.38	71.10	0.76	16.73	0.38	0.00	1.14	0.00	0.00	0.00	0.00	0.38	0.00	4.15
1359	1194	6.89	3.44	0.00	0.00	0.00	65.00	0.00	22.16	0.49	0.00	0.49	0.00	0.00	0.00	0.00	0.00	1.47	3.96
1380	812	5.22	6.34	0.00	0.00	2.98	69.02	0.00	14.92	0.37	0.00	0.74	0.00	0.00	0.00	0.00	0.37	0.00	4.22
1411	896	4.78	5.17	0.39	0.00	0.00	76.89	0.00	12.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.79
1430	793	5.14	7.47	0.00	0.00	1.40	74.29	0.00	11.21	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	2.74
1450	1189	3.09	1.76	0.00	0.00	1.32	76.10	0.00	15.92	0.00	0.00	0.88	0.00	0.00	0.00	0.00	0.00	0.44	2.94
1469	854	4.87	7.80	0.00	0.00	2.92	76.09	0.00	7.31	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.48	2.62
1490	1000	5.23	5.23	0.00	0.00	0.47	75.71	0.47	12.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	3.30
1510	1161	4.78	6.69	0.00	0.00	0.47	69.85	0.00	17.70	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.10
1530	928	0.46	1.72	0.00	0.00	1.72	63.79	0.00	15.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.20
1560	1300	17.00	0.00	0.00	0.00	0.00	65.18	0.00	16.59	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.80	1.64
1580	1157	20.98	2.46	0.00	0.00	2.88	50.20	0.00	20.16	0.00	0.00	2.05	0.41	0.00	0.00	0.00	0.00	0.82	2.76
1600	1720	10.85	1.93	0.00	0.00	5.81	50.38	0.00	31.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00
1620	1459	12.90	2.41	0.00	0.00	2.82	54.03	0.00	23.79	2.01	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	3.00
1640	1222	14.54	2.27	0.00	0.00	2.72	51.36	0.00	28.18	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	2.51
1660	995	8.13	1.43	0.00	0.00	2.39	66.50	0.00	18.66	0.47	0.00	1.91	0.00	0.00	0.00	0.00	0.00	0.47	3.05
1680	1270	4.33	5.51	0.00	0.00	1.57	52.75	0.00	35.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.10
1710	1957	4.01	1.09	0.00	0.00	1.09	69.34	0.00	23.72	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	3.85
1730	852	4.22	9.38	0.00	0.00	1.87	57.27	0.00	27.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.15
1750	1581	1.18	7.50	0.00	0.00	0.00	60.07	0.00	29.64	0.00	0.00	1.18	0.00	0.00	0.00	0.00	0.00	0.39	3.73
1779	1024	5.58	4.65	0.00	0.00	1.39	58.13	0.00	28.83	0.00	0.00	0.93	0.00	0.00	0.00	0.00	0.00	0.46	3.84
1840	819	5.63	3.28	0.00	0.00	1.87	67.60	0.00	20.65	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.46	0.00	3.33
1860	1388	0.90	4.05	0.00	0.00	0.90	67.11	0.00	26.12	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00	3.82
1880	1238	8.84	5.76	0.00	0.00	0.38	57.30	0.00	27.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	3.01
1900	1007	6.19	3.33	0.00	0.00	3.33	67.14	0.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.62
1929	775	6.45	4.14	0.00	0.00	3.68	56.22	0.00	28.57	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	3.80
1950	1156	4.80	6.73	0.00	0.00	4.32	64.42	0.00	19.23	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	3.35
1970	2000	1.25	5.00	0.00	0.00	4.16	58.75	0.00	30.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.12
1990	1306	5.40	4.50	0.00	0.00	4.50	59.45	0.00	26.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50
2009	790	6.55	5.67	0.00	0.00	5.67	64.62	0.00	17.03	0.00	0.00	0.43	0.00	0.00	0.00	0.00	0.00	0.00	2.31
2030	823	3.22	3.22	0.00	0.00	4.02	68.14	0.00	19.75	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.40	0.00	2.32
2050	679	4.46	2.23	0.00	0.00	1.33	62.05	0.00	29.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00	2.11
2080	773	0.85	0.85	0.00	0.00	5.95	65.53	0.00	25.95	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.42	0.00	1.63
2100	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.64

2120	45	10.20	26.53	0.00	0.00	2.04	36.73	0.00	24.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.55
2141	103	4.62	4.62	0.00	0.00	3.70	50.00	0.00	37.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.82
2160	19	15.78	57.89	0.00	0.00	0.00	26.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.93
2180	1074	0.30	1.50	0.00	0.00	2.10	81.38	0.00	13.21	0.00	0.00	0.30	0.00	0.00	0.90	0.00	0.30	0.00	0.00	3.77
2200	2471	0.57	0.86	0.00	0.00	0.57	82.65	0.00	15.02	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	2.00
2230	1567	1.77	0.00	0.00	0.00	2.48	78.01	0.00	17.37	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.00	2.56
2250	1589	0.69	0.00	0.00	0.00	0.69	76.92	0.00	20.97	0.00	0.00	0.34	0.00	0.00	0.34	0.00	0.00	0.00	0.00	2.22
2270	1689	1.55	0.00	0.00	0.00	2.49	79.75	0.00	14.95	0.00	0.00	0.00	0.00	0.00	1.24	0.00	0.00	0.00	0.00	2.49
2290	1263	4.16	1.25	0.00	0.00	1.25	72.91	0.00	17.08	0.00	0.00	0.41	0.00	0.00	2.91	0.00	0.00	0.00	0.00	1.42
2310	1060	9.43	0.00	0.00	0.00	0.94	63.20	0.00	16.03	0.00	0.00	1.88	0.00	0.00	8.49	0.00	0.00	0.00	0.00	1.52
2330	888	8.55	1.35	0.00	0.00	1.80	74.32	0.00	12.16	0.00	0.00	0.90	0.00	0.00	0.90	0.00	0.00	0.00	0.00	2.05
2350	1736	2.46	0.41	0.00	0.00	0.00	78.60	0.00	17.28	0.00	0.00	0.41	0.00	0.00	0.82	0.00	0.00	0.00	0.00	1.99
2379	1400	5.04	1.26	0.00	0.00	4.20	70.16	0.00	16.38	0.00	0.00	0.84	0.00	0.42	1.26	0.00	0.42	0.00	0.00	1.00
2400	230	4.30	0.00	0.00	0.00	5.26	74.16	0.00	15.31	0.00	0.00	0.47	0.00	0.00	0.47	0.00	0.00	0.00	0.00	2.00
2421	2450	5.10	0.34	0.00	0.00	1.70	68.36	0.00	17.68	0.00	0.00	2.04	0.00	0.00	1.02	0.00	0.00	0.34	0.00	2.01
2439	948	4.12	1.37	0.00	0.00	1.37	77.52	0.00	12.84	0.00	0.00	0.00	0.00	0.00	2.75	0.00	0.00	0.00	0.00	1.64
2460	1170	3.84	2.13	0.00	0.00	0.85	82.90	0.00	5.12	0.00	0.00	0.00	0.00	0.00	5.12	0.00	0.00	0.00	0.00	3.50
2480	1163	5.88	4.07	0.00	0.00	0.00	76.01	0.00	9.50	0.00	0.00	3.16	0.00	0.00	1.35	0.00	0.00	0.00	0.00	3.95
2500	1517	3.66	11.35	0.00	0.00	0.00	69.59	0.00	10.62	0.00	0.00	1.09	0.00	0.00	3.29	0.00	0.00	0.36	0.00	3.65
2531	412	4.85	1.21	0.00	0.00	0.00	60.72	0.00	24.29	0.00	0.00	0.80	0.00	0.00	8.09	0.00	0.00	0.00	0.00	3.60
2550	919	1.67	2.92	0.00	0.00	0.00	70.29	0.00	20.50	0.00	0.00	0.83	0.00	0.00	3.76	0.00	0.00	0.00	0.00	3.29
2570	617	9.45	2.70	0.00	0.00	0.00	70.27	0.00	11.71	0.00	0.00	1.80	0.00	0.00	4.05	0.00	0.00	0.00	0.00	3.14
2590	841	6.69	0.37	0.00	0.00	0.37	67.28	0.00	11.89	0.00	0.00	0.00	0.00	0.00	3.34	0.00	0.00	0.00	0.00	2.55
2610	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.59
2630	364	11.62	0.93	0.00	0.00	0.46	60.00	0.00	15.34	0.00	0.00	6.97	0.00	0.00	4.18	0.00	0.46	0.00	0.00	2.25
2650	1569	10.35	0.39	0.00	0.00	1.19	63.34	0.00	7.96	0.00	0.00	9.16	0.00	0.00	7.56	0.00	0.00	0.00	0.00	1.89
2680	1155	12.98	0.86	0.00	0.00	1.29	59.74	0.00	7.35	0.00	0.00	8.65	0.00	0.00	8.65	0.00	0.00	0.43	0.00	1.45
2700	70	12.16	1.35	0.00	0.00	0.00	62.16	0.00	16.21	0.00	0.00	0.00	0.00	0.00	6.75	1.35	0.00	0.00	0.00	1.99
2740	574	15.59	2.75	0.00	0.00	0.45	30.27	0.00	24.31	0.00	0.00	5.04	0.00	0.00	19.72	0.00	0.00	1.83	2.79	
2759	79	9.63	3.61	0.00	0.00	1.20	51.80	0.00	14.45	0.00	0.00	3.61	0.00	0.00	15.66	0.00	0.00	0.00	3.04	
2780	372	13.20	8.01	0.00	0.00	0.47	22.16	0.00	41.50	0.00	0.00	0.47	0.00	0.00	13.20	0.00	0.00	0.47	4.35	
2800	88	14.77	5.68	0.00	0.00	0.00	26.13	0.00	38.63	0.00	0.00	2.27	0.00	0.00	11.36	0.00	0.00	1.13	3.72	
2820	242	3.94	3.44	0.00	0.00	0.00	46.79	0.00	24.13	0.00	0.00	1.97	0.00	0.00	18.71	0.00	0.00	0.98	3.40	
2840	154	3.89	0.64	0.00	0.00	0.00	61.68	0.00	27.27	0.00	0.00	0.64	0.00	0.00	3.89	0.00	0.00	1.94	3.62	
2860	621	0.94	0.47	0.47	0.00	0.47	57.34	0.00	27.96	0.00	0.00	0.00	0.00	0.00	10.90	0.00	0.00	1.42	3.51	
2890	396	9.70	0.48	2.91	0.00	0.48	44.17	0.00	24.27	0.00	0.00	0.00	0.00	0.00	15.53	0.00	0.00	1.94	2.97	
2910	32	6.25	0.00	0.00	0.00	0.00	25.00	0.00	50.00	3.12	0.00	6.25	0.00	0.00	9.37	0.00	0.00	0.00	3.54	
2930	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.60	
2950	53	0.00	1.88	1.88	0.00	5.66	58.49	0.00	22.64	0.00	1.88	1.88	0.00	0.00	5.66	0.00	0.00	0.00	3.07	
2970	467	11.62	2.32	1.39	0.00	1.39	38.60	0.46	21.86	0.00	1.39	3.72	0.46	0.00	15.81	0.00	0.00	0.93	2.00	
2990	786	15.90	0.90	0.45	0.00	13.63	43.18	0.00	19.09	0.00	3.63	1.81	0.00	0.45	0.00	0.00	0.00	0.90	2.79	
3010	815	7.54	0.47	0.47	0.00	29.24	45.75	0.00	7.54	0.00	1.88	1.88	0.00	0.00	4.24	0.00	0.00	0.94	1.83	
3040	733	19.09	0.90	0.00	0.00	5.00	23.63	0.00	30.45	0.00	0.00	10.00	0.00	0.00	10.00	0.00	0.00	0.45	2.21	
3060	505	17.11	0.90	0.00	0.00	2.70	34.68	0.45	18.46	0.00	0.90	5.85	0.00	1.35	16.66	0.00	0.00	0.90	1.45	
3081	14	5.55	0.00	0.00	0.00	0.00	55.55	0.00	11.11	0.00	0.00	0.00	0.00	5.55	16.66	0.00	0.00	5.55	1.96	
3100	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.26	
3120	505	7.83	1.84	0.92	0.00	0.46	67.74	0.00	11.05	0.00	0.00	0.92	0.00	0.00	7.37	0.00	0.00	1.84	3.33	
3140	90	16.84	10.52	1.05	0.00	0.00	43.15	0.00	22.10	0.00	0.00	0.00	0.00	0.00	4.21	0.00	0.00	2.10	2.98	
3160	309	18.57	0.47	1.42	0.00	0.00	30.95	0.00	25.71	0.00	0.00	6.19	0.00	0.00	12.38	0.00	0.47	3.80	2.99	

3192	10	9 09	9.09	0.00	0.00	9.09	54.54	0.00	18.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.81
3210	526	14.46	1.65	1.23	0.00	2.06	44.21	0.00	14.46	0.00	0.00	10.74	0.00	0.00	9.50	0.00	0.41	1.23	2.62
3230	139	10.79	0.71	2.15	0.00	0.00	58.99	0.00	6.47	0.00	0.00	7.19	0.00	0.00	11.51	0.00	0.00	2.15	2.55
3250	40	13.63	0.00	0.00	0.00	0.00	47.72	0.00	11.36	0.00	0.00	9.09	2.27	0.00	11.36	0.00	2.27	2.27	1.92
3270	123	10.56	0.00	0.00	0.00	0.00	56.09	0.00	8.94	0.00	0.00	8.94	0.81	0.00	12.19	0.00	0.00	2.43	2.38
3290	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00
3311	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.60
3340	67	16.41	0.00	0.00	0.00	0.00	65.67	0.00	7.46	0.00	0.00	1.49	0.00	0.00	8.95	0.00	0.00	0.00	2.53
3359	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.18
3380	186	16.12	1.61	0.00	0.00	0.00	60.21	0.00	4.30	0.00	0.00	1.07	0.00	0.53	15.05	0.00	0.00	1.07	2.32
3399	113	31.93	0.00	0.00	0.00	0.00	42.01	0.00	3.36	0.00	0.00	0.84	0.00	0.00	10.08	0.00	0.00	3.36	1.77
3420	507	27.23	0.00	0.00	0.00	3.75	53.05	0.00	3.75	0.00	0.46	5.16	0.00	0.00	6.10	0.00	0.00	0.46	2.90
3440	2064	20.76	0.34	0.00	0.00	0.34	65.05	0.00	3.80	0.34	3.46	1.03	0.00	0.00	4.84	0.00	0.00	0.00	2.10
3460	1136	15.60	0.00	0.00	0.00	2.40	72.40	0.00	4.40	0.00	2.40	0.40	0.40	0.40	1.20	0.00	0.00	0.40	1.31
3489	40	20.83	0.00	0.00	0.00	0.00	75.00	0.00	0.00	0.00	0.00	4.16	0.00	0.00	0.00	0.00	0.00	0.00	2.79
3510	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.78
3530	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.26
3549	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.64
3570	38	36.84	0.00	0.00	0.00	0.00	42.10	0.00	0.00	0.00	0.00	10.52	0.00	0.00	10.52	0.00	0.00	0.00	3.71
3591	319	29.41	0.00	0.00	0.00	1.47	51.96	0.00	0.98	0.00	0.00	12.25	0.00	0.00	2.94	0.00	0.00	0.98	3.32
3610	826	21.07	0.44	0.00	0.00	4.03	66.81	0.00	4.48	0.00	0.89	4.48	0.00	0.00	3.13	0.00	0.00	1.34	3.08
3640	156	14.66	0.00	0.66	0.00	3.33	60.00	0.00	8.00	0.00	0.66	6.00	0.00	1.33	8.00	0.00	0.00	0.66	2.63
3660	184	24.45	0.00	0.00	0.00	0.54	45.65	0.00	5.43	0.00	0.00	8.15	0.00	0.54	15.21	0.00	0.00	0.54	2.72
3860	212	20.75	0.00	4.24	0.00	0.00	49.52	0.00	1.41	0.00	0.00	1.41	0.00	0.00	22.16	0.00	0.47	0.00	3.15
3880	584	10.81	0.00	3.60	0.00	0.90	45.94	0.00	9.45	0.00	0.00	0.00	0.00	0.90	28.37	0.00	0.00	0.00	2.79
3900	370	13.74	0.00	2.84	0.00	0.47	42.18	0.00	9.95	0.00	0.00	0.47	0.00	2.36	27.96	0.00	0.00	0.00	2.79
3920	121	22.31	0.82	0.82	0.00	0.00	33.88	0.00	1.65	0.00	0.00	4.95	0.00	0.00	34.71	0.00	0.00	0.82	2.79
3940	312	19.48	0.43	1.29	0.00	1.29	30.73	0.00	6.92	0.00	0.00	0.86	0.00	1.29	36.36	0.00	0.43	0.86	2.80
3960	328	13.63	0.00	0.90	0.00	0.90	46.81	0.00	6.81	0.00	0.00	0.90	0.00	2.72	27.27	0.00	0.00	0.00	2.77
3980	108	44.44	0.00	0.92	0.00	0.00	21.29	0.00	0.00	0.00	0.00	1.85	0.00	1.85	28.70	0.00	0.00	0.92	2.64
4011	263	22.00	0.00	0.00	0.00	0.00	25.83	0.00	3.82	0.00	0.00	1.43	0.00	0.95	45.93	0.00	0.00	0.00	2.72
4030	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.95
4050	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.01
4070	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.09
4090	169	13.45	15.20	16.95	0.00	1.16	34.50	0.00	5.26	0.00	0.00	1.75	0.00	0.00	11.69	0.00	0.00	0.00	3.14
4110	265	8.49	0.00	25.00	0.00	2.83	45.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.20	0.00	0.00	0.00	2.85
4130	54	12.96	0.00	40.74	0.00	0.00	33.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.96	0.00	0.00	0.00	1.60
4160	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.38
4180	445	22.48	0.47	33.01	0.00	0.47	28.70	0.00	0.00	0.00	0.00	1.43	0.00	0.00	13.87	0.00	0.00	0.00	2.87
4200	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.96
4220	42	18.18	0.00	52.27	0.00	0.00	18.18	0.00	6.81	0.00	0.00	0.00	0.00	0.00	4.54	0.00	0.00	0.00	2.49
4240	105	11.53	0.00	81.73	0.00	0.00	3.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.88	0.00	0.00	0.00	2.65
4260	151	23.84	1.98	54.96	0.00	0.00	14.56	0.00	0.00	0.00	0.00	0.66	0.00	0.66	3.31	0.00	0.00	0.00	2.54
4280	353	22.37	0.00	50.68	0.00	0.00	10.04	0.00	7.76	0.00	0.00	0.45	0.00	0.00	8.67	0.00	0.00	0.00	3.54
4310	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.53
4330	248	16.43	0.46	70.42	0.00	0.00	6.57	0.00	0.93	0.00	0.00	0.46	0.00	0.00	4.69	0.00	0.00	0.46	3.52
4350	506	18.10	0.41	58.84	0.00	0.82	9.87	0.00	5.76	0.00	0.00	0.41	0.00	0.00	5.34	0.00	0.00	0.41	2.42
4370	214	17.61	0.00	54.28	0.00	0.00	18.57	0.47	3.80	0.00	0.00	1.43	0.00	0.47	2.85	0.00	0.00	0.47	2.78
4390	31	6.45	0.00	70.96	0.00	0.00	19.35	0.00	0.00	0.00	0.00	3.22	0.00	0.00	0.00	0.00	0.00	0.00	2.78

4410	867	18.37	0.42	50.85	0.00	3.41	4.70	0.00	6.83	0.85	0.00	0.00	0.00	0.85	13.24	0.00	0.00	0.42	2.82
4430	155	11.61	0.00	56.77	0.00	3.22	9.67	0.00	9.03	0.00	0.00	0.00	0.00	0.00	9.03	0.00	0.00	0.64	2.27
4459	340	10.74	0.00	67.75	0.00	2.33	6.54	0.00	5.60	0.00	0.00	0.00	0.46	0.00	6.54	0.00	0.00	0.00	1.55
4479	318	18.98	0.00	75.92	0.00	0.00	1.85	0.00	0.00	0.00	0.00	0.00	0.46	0.00	1.38	1.38	0.00	0.00	0.00	1.48
4499	1137	7.40	0.00	91.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.92	0.00	0.00	0.00	2.34
4520	572	14.15	0.00	77.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.94	5.18	0.00	0.00	1.41	1.30
4540	195	7.69	0.00	89.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.00	1.02	1.02	0.00	0.00	0.51	2.27
4610	17	11.11	0.00	88.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.84
4760	140	10.71	0.00	87.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.42	0.00	0.00	0.00	2.64
4781	342	20.00	0.00	72.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	6.34	0.00	0.00	0.48	1.64
4800	510	22.05	0.00	68.13	0.00	0.00	0.00	0.00	0.49	0.00	0.00	1.47	0.98	0.00	6.37	0.00	0.00	0.49	1.08
4830	109	28.44	0.00	63.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.75	0.00	1.83	2.75	0.00	0.00	0.91	1.58
4850	11	18.18	0.00	63.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.09	0.00	0.00	9.09	0.00	0.00	0.00	1.48
4870	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.37
4890	14	13.33	0.00	80.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.66	0.00	0.00	0.00	1.50
4910	10	30.00	0.00	70.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.23
4930	33	15.15	0.00	75.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.09	0.00	0.00	0.00	3.07
4950	12	16.66	0.00	66.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.33	0.00	8.33	0.00	0.00	0.00	0.00	2.51
4980	515	24.87	0.00	62.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.98	0.00	2.98	4.97	0.00	0.99	0.49	1.79
5000	1312	22.86	0.00	40.35	0.00	9.41	0.00	0.00	0.00	0.00	0.00	6.72	0.00	0.89	17.48	0.44	0.89	0.89	1.90
5021	313	26.38	0.00	57.87	0.00	1.38	0.00	0.00	0.00	0.00	0.00	5.09	0.00	0.00	6.48	0.00	0.46	2.31	2.17
5040	1015	27.09	0.00	61.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.95	0.00	0.00	7.38	0.00	0.00	0.98	2.20
5060	412	11.90	0.00	83.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.42	0.00	0.47	2.38	0.00	0.00	0.00	1.69
5080	28	13.79	0.00	65.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.68	0.00	0.00	0.00	2.62
5100	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.38
5130	243	18.69	0.00	70.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.46	0.46	9.34	0.00	0.00	0.00	2.05
5150	1150	8.21	0.00	87.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.86	0.00	0.00	0.00	3.36
5170	296	14.21	0.00	83.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	0.00	0.00	1.47	0.00	0.00	0.00	4.29
5190	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.10
5210	605	12.50	0.00	73.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89	0.44	0.44	11.60	0.00	0.00	0.89	1.87
5230	773	17.24	0.00	67.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	13.36	0.00	0.00	1.29	1.29
5250	570	23.22	0.00	63.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.36	0.47	0.00	8.53	0.00	0.00	1.42	1.07
5280	641	19.72	0.00	64.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.91	12.84	0.00	0.00	1.83	1.62
5300	26	50.00	0.00	42.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.69	0.00	0.00	0.00	1.98
5320	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.30
5340	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.44
5359	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.60
5380	739	18.34	0.43	66.37	0.00	0.00	0.87	0.00	0.00	0.00	0.00	1.74	0.00	0.00	11.35	0.00	0.43	0.43	3.49
5400	1437	11.72	0.00	63.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.36	0.00	23.80	0.00	0.36	0.36	3.33
5430	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.10
5450	313	24.07	0.00	66.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	7.87	0.00	0.00	1.38	2.85
5469	41	43.90	0.00	53.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.43	0.00	0.00	0.00	3.96
5490	98	35.71	0.00	56.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.02	0.00	0.00	7.14	0.00	0.00	0.00	3.00
5510	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.50
5530	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.11
5550	226	33.18	4.42	51.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.44	0.00	9.29	0.00	0.00	0.88	2.30
5580	20	80.00	5.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.36
5600	817	20.00	2.44	57.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	0.00	0.00	0.40	

APPENDIX II

R-MODE CLUSTER ANALYSIS

COSINE SIMILARITY COEFFICIENT MATRIX

Cosine Similarity Coefficient Matrix

Variable	LEPTO	PELAG	DORON	HUXLE	APERT	CARIB	MUELL	OCEAN
PELAG	.4717							
DORON	.5114	.0099						
HUXLE	.2427	.5092	.0001					
APERT	.2987	.2489	.0434	.1125				
CARIB	.4168	.2151	.0430	.0320	.3741			
MUELL	.1036	.0672	.0436	.0383	.0496	.1597		
OCEAN	.5028	.6176	.0168	.3205	.5266	.5110	.1238	
PROTO	.0923	.0309	.0230	.0000	.1096	.1592	.0558	.1860
ROTA	.1570	.0098	.0028	.0000	.3546	.2306	.1251	.0803
KAMPT	.5499	.3121	.1742	.1761	.3074	.3999	.1183	.4637
DISCO	.1796	.0046	.1759	.0000	.0228	.1201	.0565	.0485
JAPON	.2573	.0156	.2570	.0110	.0646	.1280	.0533	.0687
LACUN	.5408	.0365	.3606	.0000	.1195	.3799	.0950	.1668
CLAVI	.1063	.0862	.0242	.0146	.1167	.0895	.0000	.0907
PULCH	.2408	.1936	.0957	.1933	.3269	.2003	.0985	.2458
MIRAB	.4794	.2667	.1903	.2389	.2714	.3234	.1170	.4027

Variable	PROTO	ROTA	KAMPT	DISCO	JAPON	LACUN	CLAVI	PULCH
ROTA	.0450							
KAMPT	.1249	.1261						
DISCO	.0000	.0846	.2463					
JAPON	.0148	.0597	.2267	.0161				
LACUN	.0793	.1005	.3992	.2051	.3341			
CLAVI	.0000	.0000	.0878	.0000	.0206	.0811		
PULCH	.0751	.0000	.3221	.4511	.1043	.1907	.0954	
MIRAB	.0495	.1060	.4206	.2405	.2670	.3999	.0495	.3151